FINAL REPORT OF SPECIFIC PURPOSE LIDAR SURVEY

LiDAR, Breaklines and Contours for

Okaloosa County, Florida

State of Florida

Division of Emergency Management

Contract 07-HS-34-14-00-22-469

Task Order 20070525-492718a

PDS Task Order B

October 30, 2009

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LiDAR-Generated Breaklines and Contours for Okaloosa County, Florida

Contract 07-HS-34-14-00-22-469; T.O. No. 20070525-492718a, Task Order B

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Report of Specific Purpose LiDAR Survey, LiDAR-Generated Breaklines and Contours Okaloosa County, Florida

Type of Survey: Specific Purpose Survey

This report pertains to a Specific Purpose LiDAR Survey of Okaloosa County, Florida, conducted in the summer of 2007, and breaklines and contours generated in 2007 and 2008, for the Florida Division of Emergency Management (FDEM).

The LiDAR dataset, breaklines and contours were prepared by the Program and Data Solutions (PDS) team under FDEM contract 07-HS-34-14-00-22-469, Task Order 20070525-492718a (PDS Task Order B). The LiDAR dataset of Okaloosa County was acquired by The Sanborn Map Company (Sanborn) in the summer of 2007 and processed to a bare-earth digital terrain model (DTM); it was produced to FDEM vertical accuracy specifications that differ from NOAA specifications in the adjoining LiDAR datasets of Walton County and Santa Rosa County, as summarized in Table 1.

Table 1. Comparison of FDEM and NOAA Vertical Accuracy Criteria

Vertical Accuracy Criteria	FDEM Specifications	NOAA Specifications
Fundamental Vertical Accuracy (FVA) at the 95% confidence level, in open terrain (non-vegetated) land cover only	**≤ 18.2-cm** (0.60-ft) (based on $RMSE_z$ of 9.25-cm x 1.9600)	**≤ 29.4-cm** (0.96-ft) (based on $RMSE_z$ of 15-cm x 1.9600)
Consolidated Vertical Accuracy (CVA) at the 95% confidence level, in all land cover categories combined	**≤ 36.3-cm** (1.19-ft) (based on 95th percentile) or $RMSE_z$ of 18.5-cm x 1.9600	**≤ 36.3-cm** (1.19-ft) (based on 95th percentile) or $RMSE_z$ of 18.5-cm x 1.9600

Under Task Order B, this is one of 12 similar county reports prepared by the PDS team of coastal areas along the Florida Panhandle, from Escambia County through Levy County, considered by FDEM to be vulnerable to hurricane tidal surges. Of these 12 reports, those for coastal Escambia, Santa Rosa, Walton and northern Bay County are based on LiDAR data previously acquired in support of the Northwest Florida Water Management District (NWFWMD) and produced to different accuracy specifications as indicated in Table 1 and to different point densities. The LiDAR datasets produced for Escambia, Santa Rosa and Walton counties were produced by three different NOAA contractors, but with independent QA/QC by Dewberry.

The reports for coastal areas of Okaloosa County, as well as Bay, Gulf, Franklin, Wakulla, Jefferson, Taylor, Dixie, and Levy counties are based on LiDAR data acquired in 2007 by the PDS team under the referenced FDEM contract, produced to the more-rigorous FDEM specifications. Detailed breaklines and contours were produced by the PDS team for areas to be mapped/improved as identified by a tile index provided by FDEM to PDS. Each tile covers an area of 5000 ft by 5000 ft. The map at Appendix A displays the 180 tiles of Okaloosa County for which LiDAR DTMs and LiDAR-derived breaklines and contours were produced by the PDS team under Task Order B. To avoid double counting, tiles on the county border with Walton County and Santa Rosa County were delivered only in one county dataset ─ normally whichever county included the majority of the area of each 5000 ft by 5000 ft tile.

Rather than describe only the data provided of Okaloosa County in isolation, this report also explains the differences between LiDAR datasets acquired of Escambia, Santa Rosa and Walton counties and those of other counties in the Florida Panhandle produced to different specifications. In addition to the differences in vertical accuracy criteria, summarized in Table 1, there are also differences in the geodetic control used for the different contracts, and there are different point densities between the data acquired to NOAA specifications and data acquired to FDEM Baseline Specifications:

- For the nine new counties mapped by the PDS team for FDEM in the Florida Panhandle under Task Order B, a rigorous geodetic control network was established by the PDS team for all coastal counties between Okaloosa and Levy counties, but excluding Walton County which had been previously mapped by NOAA. Thus, the survey control used for Escambia, Santa Rosa, and Walton counties may differ from the geodetic control network established for the nine other counties in the Panhandle. Primarily because a rigorous geodetic control network was surveyed by the PDS team for the nine new counties, it is expected that there will be differences in the elevations of topographic surfaces between counties, primarily around the boundaries of Escambia, Santa Rosa and Walton counties where the 2006 LiDAR datasets, controlled to older survey control, merge with the 2007 LiDAR datasets controlled to the new geodetic control network established by the PDS team.

- For the nine new counties, including Okaloosa County, the FDEM Baseline Specifications require a maximum post spacing of 4 feet, i.e., an average point density of less than 1 point per square meter. However, the PDS team required a much higher point density of its subcontractors in order to increase the probability of penetrating dense foliage during the mandated summer acquisition; with nominal post spacing of 0.7 meters per flight line and 50% sidelap between flight lines, the average point density is 4 points per square meter. The NOAA specifications for Escambia County, Santa Rosa County, Walton County, and northern Bay County, required a nominal post spacing of 2 meters, yielding an average point density of 0.25 points per square meter. The significance of this difference is that the nine new counties acquired for FDEM, including Okaloosa County, have LiDAR point densities approximately 16 times higher than the LiDAR point densities in Escambia County, Santa Rosa County, Walton County, and northern Bay County. With higher point density there is a greater probability of penetrating dense vegetation and minimizing areas defined as "low confidence areas."

The PDS Team

PDS is a Joint Venture consisting of PBS&J, Dewberry, and URS Corp:

- PBS&J provided local client liaison in Tallahassee. PBS&J was also responsible for the overall ground survey effort including management of field survey subcontractors – Allen Nobles & Associates, Inc. (ANA) and Diversified Design & Drafting Services, Inc. (3DS) – which performed the geodetic control surveys and quality assurance/quality control (QA/QC) checkpoint surveys used for independent accuracy testing by Dewberry and URS. These surveyors executed a network adjustment of control points used throughout the Florida Panhandle. It was important to execute this network adjustment because of widely-held concerns that the survey control was deficient in the Florida Panhandle counties. Mr. Glenn Bryan, PSM, of PBS&J, and Mr. Brett Wood, PSM, of 3DS, were the technical leads for the control surveys and QA/QC surveys.

- Dewberry was responsible for the overall Work Plan and aerial survey effort for the nine new counties, including management of LiDAR subcontractors that performed the LiDAR data acquisition and post-processing and produced LAS classified data. A staff of QA/QC specialists at Dewberry's Fairfax (VA) office performed quality assessments of the breaklines and contours. Dewberry served as the single point of contact with FDEM. Dr. David Maune, PSM, was Dewberry's technical lead for the digital orthophoto and LiDAR surveys and derived products. Under separate contract with NOAA, Dr. Maune had previously served as Dewberry's Quality Manager for its independent QA/QC of LiDAR data produced by NOAA for the NWFWMD of Escambia, Santa Rosa, and Walton counties.

- URS Corp. was responsible for data management and information management. URS developed the GeoCue Distributed Production Management System (DPMS), managed and tracked the flow of data, performed independent accuracy testing and quality assessments of FDEM's new LiDAR data acquired in 2007, tracked and reported the status of individual tiles during production, and produced all final deliverables for FDEM. Mr. Robert Ryan, CP, of URS, was the technical lead for this effort.

Name of Company in Responsible Charge

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Survey Area

The project area for this report encompasses approximately 161.4 square miles within Okaloosa County and small adjoining areas of Walton County and Santa Rosa County.

Map Reference

There are no hardcopy map sheets for this project. The map at Appendix A provides graphical reference to the 5000-ft x 5000-ft tiles covered by this report.

Summary of FDEM Baseline Specifications

All new data produced for FDEM under the referenced contract are required to satisfy the Florida Baseline Specifications, included as appendices to PDS's Task Order B, dated May 23, 2007, from FDEM. To expedite production, the Florida Baseline Specifications were modified by FDEM to require new LiDAR data acquisition during the summer of 2007 (leaf-on) as opposed to the normal leaf-off.

Task Order B presented demanding technical challenges for the PDS team because the existing geodetic control monuments in the Florida Panhandle are believed to be the most inaccurate in Florida, with elevation discrepancies as much as several feet; and some areas in the Panhandle are subject to subsidence. LiDAR elevations produced relative to some survey control monuments are believed to differ by as much as several feet from LiDAR elevations produced relative to other control monuments in the Panhandle. This caused a new geodetic control network to be established by the PDS team for the counties to be newly surveyed, but without adjusting the geodetic control monuments used for Escambia

County, Santa Rosa County, Walton County, and northern Bay County for which existing LiDAR data was used "as is."

The official State Plane Coordinate System tiling scheme was provided by FDEM to the PDS team on July 10, 2007 for Florida's North Zone and West Zone. The Okaloosa County tiling footprint graphic is shown at Appendix A.

The Florida Baseline Specifications required the LiDAR data to be collected using an approved sensor with a maximum field of view (FOV) of 20° on either side of nadir, with GPS baseline distances limited to 20 miles, with maximum post spacing of 4 feet in unobscured areas for random point data, and with vertical root mean square error ($RMSE_z$) $\leq$ 0.30 ft and Fundamental Vertical Accuracy (FVA) $\leq$ 0.60 ft at the 95% confidence level in open terrain (bare-earth and low grass); this accuracy is equivalent to 1 ft contours in open terrain when tested in accordance with the National Map Accuracy Standard (NMAS). In other land cover categories (brush lands and low trees, forested areas fully covered by trees, and urban areas), the Florida Baseline Specifications required the LiDAR data's $RMSE_z$ to be $\leq$ 0.61 ft with Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) $\leq$ 1.19 ft at the 95% confidence level; this accuracy is equivalent to 2 ft contours when tested in accordance with the NMAS. *Low confidence areas*, originally called *obscured vegetated areas,* are defined for areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

The Florida Baseline Specifications also required the horizontal accuracy to meet or exceed 3.8 feet at the 95% confidence level, using $RMSE_r$ x 1.7308. This means that the horizontal (radial) RMSE ($RMSE_r$) must meet or exceed 2.20 ft. This is the horizontal accuracy required of maps compiled at a scale of 1:1,200 (1" = 100') in accordance with the traditional National Map Accuracy Standard.

To meet and exceed these specifications for the nine new county LiDAR datasets, the PDS team established the following more-rigorous specifications for its LiDAR subcontractors:

- Instead of a 20° FOV on either side of nadir, the PDS team limited the FOV to 18°
- Instead of GPS baselines $\leq$ 20 miles, the PDS team limited baseline lengths to $\leq$ 20 km, except in one small isolated area where the baseline length was approximately 23 km (14 miles).
- Instead of 4 foot post spacing which yields an average of 0.67 points per m^2, the PDS team chose 0.7 m point spacing and 50% sidelap that yields an average of more than 4 points per m^2. Thus, the PDS team's average point density is nearly 6 times higher than required by FDEM, greatly increasing the probability of LiDAR points penetrating through dense vegetation so as to minimize areas defined as *low confidence areas*. The PDS team defines *low confidence areas* as vegetated areas of ½ acre or larger that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. Such areas indicate where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

The first deliverable is LiDAR mass points, delivered to LAS 1.1 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, includes LiDAR points in overlapping flight lines
- Class 9 = Water, includes LiDAR points in overlapping flight lines

* Class 12 = Overlap, including areas of overlapping flight lines which have been deliberately removed from Class 1 because of their reduced accuracy.

Table 2 compares the LiDAR LAS classes specified by the FDEM and NOAA specifications.

Table 2. Comparison of FDEM and NOAA LAS Classes

FDEM LAS Classes	NOAA LAS Classes
Class 1 – Unclassified, including vegetation, buildings, bridges, piers Class 2 – Ground points (used for contours) Class 7 – Noise Class 9 – Water[1] Class 12 – Overlap points deliberately removed	Class 1 – Unclassified Class 2 – Ground points (used for contours) Class 9 – Water

For each 500 square mile area within the nine new county datasets, a total of 120 "blind" QA/QC checkpoints were surveyed, totally unknown to (i.e., "blind" from) the LiDAR subcontractors. Each set of 120 QA/QC checkpoints had the goal to include 30 checkpoints in each of the following four land cover categories:

* Category 1 = bare-earth and low grass
* Category 2 = brush lands and low trees
* Category 3 = forested areas fully covered by trees
* Category 4 = urban areas

In a few cases, there were insufficient dispersed areas to acquire 30 QA/QC checkpoints for one or more land cover categories; when this occurred, Dewberry advised the surveyors to select additional QA/QC checkpoints for land cover categories that were predominant in the area and therefore more representative of the area being tested.

The following vertical accuracy guidelines were specified by the Florida Baseline Specifications:

* In category 1, the $RMSE_z$ must be $\leq$ 0.30 ft ($Accuracy_z \leq$ 0.60 ft at the 95% confidence level); $Accuracy_z$ in Category 1 refers to Fundamental Vertical Accuracy (FVA) which defines how accurate the elevation data are when not complicated by asphalt or vegetation that may cause elevations to be either lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 1 ft contours in non-vegetated terrain.
* In category 2, the $RMSE_z$ must be $\leq$ 0.61 ft ($Accuracy_z \leq$ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 2 refers to Supplemental Vertical Accuracy (SVA) in brush lands and low trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to be lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.

[1] Infrared radiation from LiDAR is partially absorbed by water, and all elevations in LAS Class 9 should be recognized as unreliable and treated accordingly.

- In category 3, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 3 refers to Supplemental Vertical Accuracy (SVA) in forested areas fully covered by trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to be lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In category 4, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 4 refers to Supplemental Vertical Accuracy (SVA) in urban areas typically paved with asphalt and defines how accurate the elevation data are when complicated by asphalt that frequently causes elevations to be lower than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In all land cover categories combined, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in all categories combined refers to Consolidated Vertical Accuracy (CVA).
- The terms FVA, SVA and CVA are explained in Chapter 3, *Accuracy Standards & Guidelines*, of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published by the American Society for Photogrammetry and Remote Sensing (ASPRS), January, 2007.

A second major deliverable consists of nine types of breaklines, produced in accordance with the PDS team's Data Dictionary at Appendix C:

1. Coastal shoreline features
2. Single-line hydrographic features
3. Dual-line hydrographic features
4. Closed water body features
5. Road edge-of-pavement features
6. Bridge and overpass features
7. Soft breakline features
8. Island features
9. Low confidence areas

Another major deliverable includes both one-foot and two-foot contours, produced from the mass points and breaklines, certified to meet or exceed NSSDA standards for one-foot contours. Two-foot contours within obscured vegetated areas are not required to meet NSSDA standards. These contours were also produced in accordance with the PDS team's Data Dictionary at Appendix C.

Table 3 is included below for ease in understanding the accuracy requirements when comparing the traditional National Map Accuracy Standard (NMAS) and the newer National Standard for Spatial Data Accuracy (NSSDA). This table is extracted from Table 13.2 of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in January, 2007 by ASPRS. The traditional NMAS uses Vertical Map Accuracy Standard (VMAS) to define vertical accuracy at the 90% confidence level, whereas the NSSDA uses $Accuracy_z$ to define vertical accuracy at the 95% confidence level. Both the VMAS and $Accuracy_z$ are computed with different multipliers for the very same $RMSE_z$ value which represents vertical accuracy at the 68% confidence level for each equivalent contour interval specified. The term $Accuracy_z$ (vertical accuracy at the 95% confidence level) is comparable to the terms described below as Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and

Supplemental Vertical Accuracy (SVA) which also define vertical accuracy at the 95% confidence level. In open (non-vegetated) terrain, $Accuracy_z$ is exactly the same as FVA (both computed as $RMSE_z$ x 1.9600) because there is no logical justification for elevation errors to depart from a normal error distribution. In vegetated areas, vertical accuracy at the 95% confidence level ($Accuracy_z$) can also be computed as $RMSE_z$ x 1.9600; however, because vertical errors do not always have a normal error distribution in vegetated terrain, alternative guidelines from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) allow the 95th percentile method to be used (as with the CVA and SVA) to report the vertical accuracy at the 95% confidence level in land cover categories other than open terrain.

Table 3. Comparison of NMAS/NSSDA Vertical Accuracy

NMAS Equivalent Contour Interval	**NMAS** VMAS (90 percent confidence level)	**NSSDA** $RMSE_z$ (68 percent confidence level)	**NSSDA** $Accuracy_z$, (95 percent confidence level)
1 ft	0.5 ft	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm
2 ft	1.0 ft	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm

The next major deliverable includes metadata compliant with the Federal Geographic Data Committee's (FGDC) Content Standard for Spatial Metadata in an ArcCatalog-compatible XML format. Copies of all survey reports, including this Report of Specific Purpose LiDAR Survey, must be delivered in PDF format as attachments to the metadata.

The last major deliverable includes the Vertical Accuracy Report of Okaloosa County, based on independent comparison of the LiDAR data with the QA/QC checkpoints, surveyed and tested in accordance with guidelines of the National Standard for Spatial Data Accuracy (NSSDA), American Society for Photogrammetry and Remote Sensing (ASPRS), Federal Emergency Management Agency (FEMA), and National Digital Elevation Program (NDEP), and using the QA/QC checkpoints surveyed by Dewberry and listed at Appendix E.

Instead of delivering one vertical accuracy report, using 120 QA/QC checkpoints for each 500 square miles of the project area, separate reports are delivered for each county. Therefore, individual county vertical accuracy reports may be based on fewer than or more than 120 QA/QC checkpoints, depending on whether the area mapped in each county is smaller than or larger than 500 square miles. Regardless, the average density of QA/QC checkpoints remains the same on average for each countywide report.

Datums and Coordinates: North American Datum of 1983 (NAD 83)/HARN for horizontal coordinates and North American Vertical Datum of 1988 (NAVD 88) for vertical coordinates. All coordinates are Florida State Plane Coordinate System (SPCS) in U.S. Survey Feet. All counties listed are in the Florida SPCS North Zone, except for Levy County which is delivered in both Florida SPCS North and West Zones. Levy County is normally in the West Zone but the LiDAR data are also delivered in the North Zone for ease in merger with all Panhandle counties for SLOSH modeling of all counties from Escambia through Levy.

Appendix I to this report provides the Geodatabase structure for all digital vector deliverables in Okaloosa County.

Acronyms and Definitions

3DS	Diversified Design & Drafting Services, Inc.
Accuracy_r	Horizontal (radial) accuracy at the 95% confidence level, defined by the NSSDA
Accuracy_z	Vertical accuracy at the 95% confidence level, defined by the NSSDA
ANA	Allen Nobles & Associates, Inc.
ASFPM	Association of State Floodplain Managers
ASPRS	American Society for Photogrammetry and Remote Sensing
CFM	Certified Floodplain Manager (ASFPM)
CMAS	Circular Map Accuracy Standard, defined by the NMAS
CP	Certified Photogrammetrist (ASPRS)
CVA	Consolidated Vertical Accuracy, defined by the NDEP and ASPRS
DEM	Digital Elevation Model (gridded DTM)
DTM	Digital Terrain Model (mass points and breaklines to map the bare earth terrain)
DSM	Digital Surface Model (top reflective surface, includes treetops and rooftops)
FDEM	Florida Division of Emergency Management
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FOV	Field of View
FVA	Fundamental Vertical Accuracy, defined by the NDEP and ASPRS
GS	Geodetic Surveyor
GIS	Geographic Information System Surveyor
LAS	LiDAR data format as defined by ASPRS
LiDAR	Light Detection and Ranging
LMSI	Laser Mapping Specialists Inc.
MHHW	Mean Higher High Water
MHW	Mean High Water, defines official shoreline in Florida
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NMAS	National Map Accuracy Standard
NOAA	National Oceanic and Atmospheric Administration
NSSDA	National Standard for Spatial Data Accuracy
NSRS	National Spatial Reference System
NWFWMD	Northwest Florida Water Management District
PDS	Program & Data Solutions, joint venture between PBS&J, Dewberry and URS Corp
PS	Photogrammetric Surveyor
PSM	Professional Surveyor and Mapper (Florida)
QA/QC	Quality Assurance/Quality Control
RMSE_h	Vertical Root Mean Square Error (RMSE) of ellipsoid heights
RMSE_r	Horizontal (radial) Root Mean Square Error (RMSE) computed from RMSE_x and RMSE_y
RMSE_z	Vertical Root Mean Square Error (RMSE) of orthometric heights
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SRWMD	Suwannee River Water Management District
SVA	Supplemental Vertical Accuracy, defined by the NDEP and ASPRS

TIN	Triangulated Irregular Network
VMAS	Vertical Map Accuracy Standard, defined by the NMAS

Ground Surveys and Dates

Past experience with control in the Florida Panhandle area indicated a need to improve the accuracy of the existing survey monuments. For the nine newly-mapped counties in the Florida Panhandle, including Okaloosa County, the PDS team established a geodetic control network to provide accurate and consistent horizontal and vertical control for LiDAR and photogrammetric mapping using GPS technology. The project consisted of a Primary and two Secondary control networks supporting the mapping of approximately 6,113 square miles located in Northwest Florida. PBS&J managed the overall ground survey effort including management of field survey subcontractors, Allen Nobles & Associates, Inc. (ANA) and Diversified Design & Drafting Services, Inc. (3DS), which performed control surveys and QA/QC checkpoint surveys used for independent accuracy testing, and executed a network adjustment of control points used throughout the Florida panhandle.

The Primary network stations (see Figure 1) were used as base stations supporting the airborne GPS data acquisition, and as a consistent control framework for the more densely spaced Secondary control networks, and all subsequent control surveying activity on the project. They were setup at 40 kilometer spacing per the 2 centimeter requirements for Primary Control stated in the NOS NGS-58. The Primary Control network consisted of 55 stations, including 10 Continuously Operating Reference Stations (CORS), 27 existing monuments from the National Spatial Reference System (NSRS) and 18 new monuments set so as to limit LiDAR GPS baseline lengths to 20 Km relative to GPS base stations on either side of stations spaced ≈40 Km apart. Third order differential leveling was used to establish elevations on 20 Primary network stations in specific areas where published vertical stations could not be occupied directly with GPS. A minimally constrained (free) Least Squares adjustment was run to verify the internal accuracy of the Primary network. After evaluating and removing any outliers, a final free adjustment was generated, consisting of 191 independent vectors. The input error estimates were scaled by a factor of 14.90 which resulted in a properly weighted adjustment with a variance factor of 1.0154, with no flagged residuals. A constrained (fixed) 3-D horizontal adjustment was run using the same input error estimates as were used in the free adjustment; the variance factor was 1.3712 and there were no flagged residuals. A constrained (fixed) 1-D vertical adjustment was run using the same input error estimates as were used in the free adjustment; Station BE3991 was fixed in latitude, longitude and orthometric height; the variance factor was 1.2866 and there were no flagged residuals.

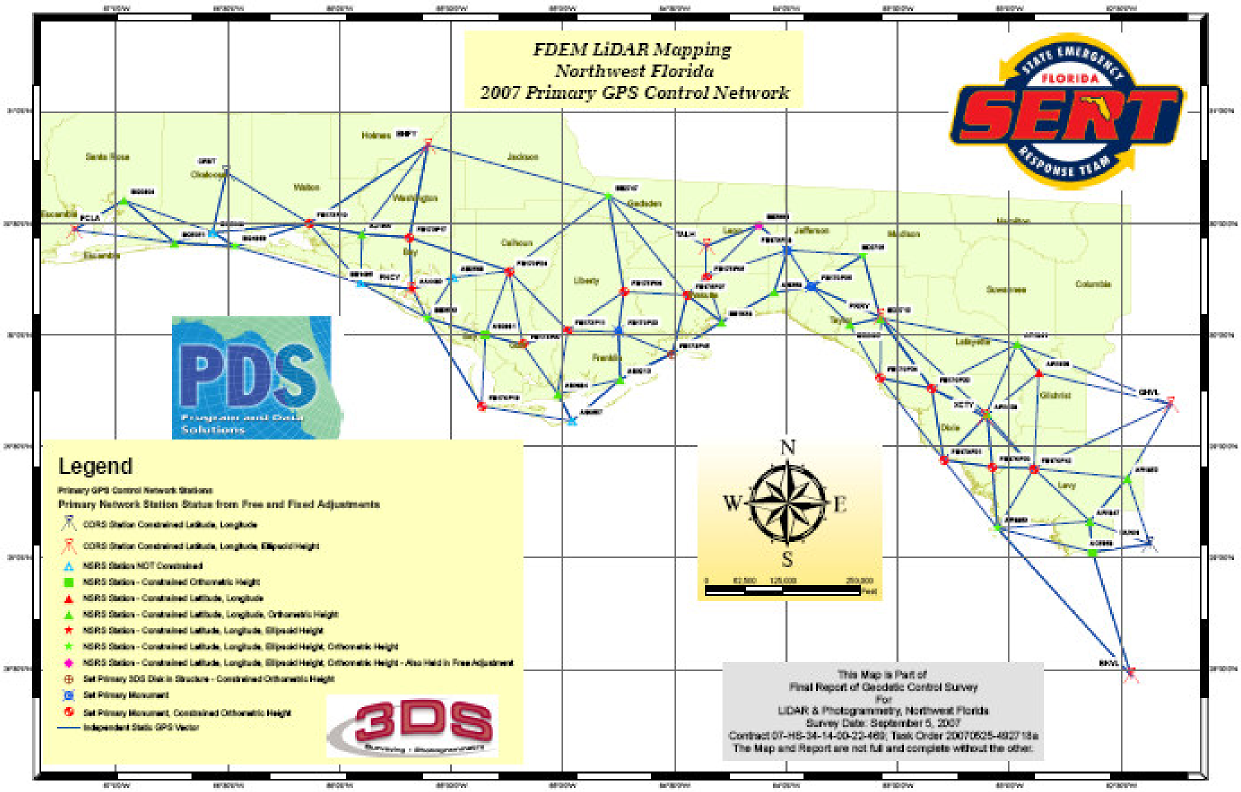


Figure 1. Primary Control Network

The Secondary network stations (see Figure 2) were used to support the measurement of both LiDAR and orthophoto QA/QC checkpoint sites. They were setup at 15 kilometer spacing per the 2 centimeter requirements for Secondary Control stated in NOS NGS-58.

The first Secondary Control network consisted of 4 stations in the Okaloosa County area. The second Secondary Control network consisted of all remaining mapping areas in the Florida Panhandle. The Secondary Control networks included a total of 80 control points, including 16 recovered NSRS monuments, 2 recovered DNR monuments, and 62 new monuments set for this network. A minimally constrained (free) Least Squares adjustment was run to verify the internal accuracy of the Secondary networks. After evaluating and removing any outliers, a final free adjustment was generated. This final free adjustment consisted of 254 independent vectors. The input error estimates were scaled by a factor of 6.234, which resulted in a properly weighted adjustment with a variance factor of 1.000; there were no flagged residuals. A constrained (fixed) 3-D horizontal adjustment was run using the same input error estimates as were used in the free adjustment; the variance factor was 1.6339 and there were six flagged residuals. A constrained (fixed) 1-D vertical adjustment was run using the same input error estimates as were used in the free adjustment; Station BE3991 was fixed in latitude, longitude and orthometric height; the variance factor was 1.2136 and there were no flagged residuals.

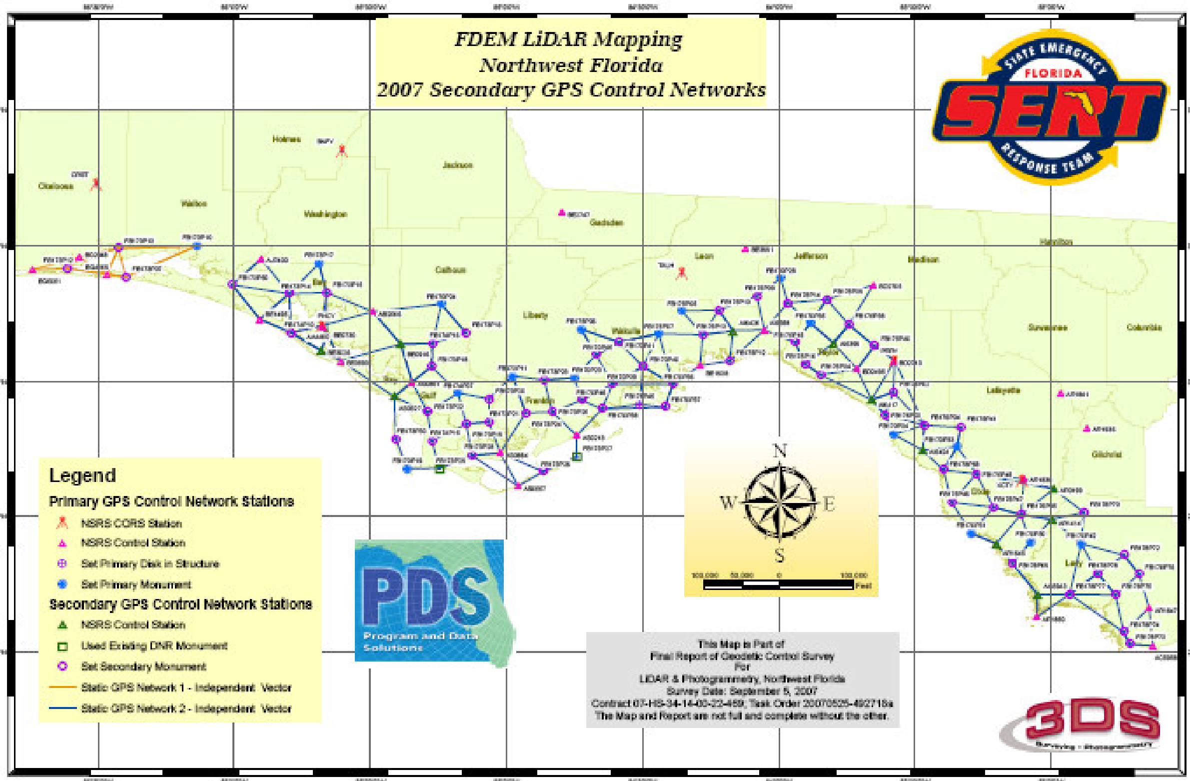


Figure 2. Secondary Control Networks

These GPS ground surveys were executed between May and September 2007. Full details are documented in 3DS's "Final Report of Geodetic Control Survey for LiDAR and Photogrammetry, Northwest Florida," dated March 13, 2008.

The QA/QC checkpoints used for this county are listed at Appendix E.

LiDAR Aerial Survey Areas and Dates

Sanborn collected the LiDAR data for Okaloosa County during the summer of 2007.

LiDAR Processing Methodology

A LiDAR processing report from Sanborn is included at Appendix D.

LiDAR Vertical Accuracy Testing

URS performed the LiDAR vertical accuracy assessment for Okaloosa County in accordance with *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, May 24, 2004, and Section 1.5 of the *Guidelines for Digital Elevation Data*, published by the National Digital Elevation Program (NDEP), May 10, 2004. These guidelines call for the mandatory determination of Fundamental Vertical Accuracy (FVA) and Consolidated Vertical Accuracy (CVA), and the optional determination of Supplemental Vertical Accuracy (SVA). NOAA's accuracy specifications are compared with FDEM's accuracy specifications at Table 1. NOAA's checkpoint requirements are compared with FDEM's checkpoint requirements at Table 4.

Table 4. Comparison of FDEM and NOAA Checkpoint Requirements

	FDEM Specifications	**NOAA Specifications**
Land cover categories tested by QA/QC checkpoints	Four land cover categories tested: 1. Open terrain; bare-earth, low grass 2. Brush lands and low trees 3. Forested areas 4. Urban, built-up areas	Five land cover categories tested: 1. Open terrain; bare-earth, low grass 2. Weeds and crops 3. Scrub 4. Forested areas 5. Urban, built-up areas
Number of checkpoints per category	20 checkpoints, per category, for each 500 square mile area	20 checkpoints, per category, for each countywide dataset

The LiDAR dataset of Okaloosa County, delivered in May of 2008, passed the accuracy testing by URS as documented at Appendices E and F.

Fundamental Vertical Accuracy (FVA) is determined with QA/QC checkpoints located only in open terrain (grass, dirt, sand, and rocks) where there is a high probability that the LiDAR sensor detected the bare-earth ground surface, and where errors are expected to follow a normal error distribution. With a normal error distribution, the FVA at the 95 percent confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. The FVA is the same as $Accuracy_z$ at the 95% confidence level (for open terrain), as specified in Appendix 3-A of the *National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998, see http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3. For FDEM, including Okaloosa County, the FVA standard is .60 feet, corresponding to an $RMSE_z$ of 0.30 feet or 9.25 cm, the accuracy expected from 1-foot contours. ***In Okaloosa County, the $RMSE_z$ in bare earth and low grass equaled 0.25 ft compared with the 0.30 ft specification of FDEM; and the FVA computed using $RMSE_z$ x 1.9600 was equal to 0.49 ft, compared with the 0.60 ft specification of FDEM.***

Consolidated Vertical Accuracy (CVA) is determined with all checkpoints, representing open terrain and all other land cover categories combined. If errors follow a normal error distribution, the CVA can be computed by multiplying the consolidated $RMSE_z$ by 1.9600. However, because bare-earth elevation errors often vary based on the height and density of vegetation, a normal error distribution cannot be assumed, and $RMSE_z$ cannot necessarily be used to calculate the 95 percent confidence level. Instead, a nonparametric testing method, based on the 95th percentile, may be used to determine CVA at the 95 percent confidence level. NDEP guidelines state that errors larger than the 95th percentile should be documented in the quality control report and project metadata. For FDEM, the CVA specification for all classes combined should be less than or equal to 1.19 feet; this same CVA specification was used by

NOAA. ***In Okaloosa County, the CVA computed using $RMSE_z$ x 1.9600 was equal to 0.76 ft, compared with the 1.19 ft specification of FDEM; and the CVA computed using the 95^{th} percentile was equal to 0.78 ft. URS determined that the dataset passed the CVA standard.***

Supplemental Vertical Accuracy (SVA) is determined separately for each individual land cover category, recognizing that the LiDAR sensor and post-processing may not have mapped the bare-earth ground surface, and that errors may not follow a normal error distribution. SVA specifications are "target" values and not mandatory, recognizing that larger errors in some categories are offset by smaller errors in other land cover categories, so long as the overall mandatory CVA specification is satisfied. For each land cover category, the SVA at the 95 percent confidence level equals the 95^{th} percentile error for all checkpoints in that particular land cover category. For FDEM's specification, the SVA target is 1.19 feet for each category; this same SVA target specification was used by NOAA. ***In Okaloosa County, the SVA tested as 0.38 ft in bare earth and low grass, 0.77 ft in brush and low trees, 0.74 ft in forested areas, and 0.70 ft in urban terrain. All of these four land cover categories met theirs target value of 1.19 ft or less.***

The complete LiDAR Vertical Accuracy Report for Okaloosa County is at Appendix F.

LiDAR Horizontal Accuracy Testing

The LiDAR data was compiled to meet 3.8 feet horizontal accuracy at the 95% confidence level.

Whereas FDEM baseline specifications call for horizontal accuracy testing, traditional horizontal accuracy testing of LiDAR data is not cost effective for the following reasons:

- Paragraphs 3.2.2 and 3.2.3 of the National Standard for Spatial Data Accuracy (NSSDA) states: "Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy … when a dataset, e.g., a gridded digital elevation dataset or elevation contour dataset does not contain well-defined points, label for vertical accuracy only." Similarly, in Appendix 3-C of the NSSDA, paragraph 1 explains well-defined points as follows: "A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points."
- Paragraph 1.5.3.4 of the *Guidelines for Digital Elevation Data*, published in 2004 by the National Digital Elevation Program (NDEP), states: "The NDEP does not require independent testing of horizontal accuracy for elevation products. When the lack of distinct surface features makes horizontal accuracy testing of mass points, TINs, or DEMs difficult or impossible, the data producer should specify horizontal accuracy using the following statement: *Compiled to meet __ (meters, feet) horizontal accuracy at 95 percent confidence level*."
- Paragraph 1.2, Horizontal Accuracy, of *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS) in 2004, further explains why it is difficult and impractical to test the

horizontal accuracy of LiDAR data, and explains why ASPRS does not require horizontal accuracy testing of LiDAR-derived elevation products.

- ASPRS has been actively seeking to develop cost-effective techniques to use LiDAR intensity imagery to test the horizontal accuracy of LiDAR data. As recently as May 1, 2008, at the annual conference of ASPRS, the most relevant technique for doing so was in a paper entitled "New Horizontal Accuracy Assessment Tools and Techniques for Lidar Data," presented by the Ohio DOT. Whereas the technique had research value, it was neither practical nor affordable for use in horizontal accuracy testing of FDEM data.
- Appendix A of FDEM's Baseline Specifications require 20 horizontal test points for every 500 square mile area of digital orthophotos to be produced, and Appendix B of FDEM's Baseline Specifications requires 120 vertical test points for each 500 square mile area of LiDAR data to be produced. The PDS task orders included no funding for the more-expensive horizontal checkpoints that would be certain to appear on LiDAR intensity images as clearly-defined point features.
- In addition to LiDAR system factory calibration of horizontal and vertical accuracy, each of the PDS team's LiDAR subcontractors have different techniques for field calibration checks used to determine if bore-sighting is still accurate. Sanborn's technique, used for Okaloosa County, is explained at Appendix D. Sanborn's field calibration tests indicated the horizontal accuracy tested 2.274 feet at the 95 percent confidence level, well within FDEM's 3.8 foot specification.

LiDAR Qualitative Assessments

URS also performed the LiDAR qualitative assessment.

An assessment of the vertical accuracy alone does not yield a complete picture with regard to the usability of LiDAR data for its intended purpose. It is very possible for a given set of LiDAR data to meet the accuracy requirements, yet still contain artifacts (non-ground points) in the bare-earth surface, or a lack of ground points in some areas that may render the data, in whole or in part, unsuitable for certain applications.

Based on the extremely large volume of elevation points generated, it is neither time efficient, cost effective, nor technically practical to produce a perfectly clean (artifact-free) bare-earth terrain surface. The purpose of the LiDAR Qualitative Assessment Report (see Appendix G) is to provide a qualitative analysis of the "cleanliness" of the bare-earth terrain surface for use in supporting riverine and coastal analysis, modeling, and mapping.

The main software programs used by URS in performing the bare-earth data cleanliness review include the following:

- *GeoCue*: a geospatial data/process management system especially suited to managing large LiDAR data sets
- *TerraModeler*: used for analysis and visualization
- *TerraScan*: runs inside of MicroStation; used for point classification and points file generation
- *GeoCue LAS EQC:* is also used for data analysis and edit

The following systematic approach was followed by URS in performing the cleanliness review and analysis:

- Uploaded data to the GeoCue data warehouse (enhanced data management)
  - LiDAR: cut the data into uniform tiles measuring 5,000 feet by 5,000 feet – using the State Plane tile index provided by FDEM
  - Imagery: Best available orthophotography was used to facilitate the data review. Additional LiDAR Orthos were created from the LiDAR intensity data and used for review purposes.
- Performed coverage/gap check to ensure proper coverage of the project area
  - Created a large post grid (~30 meters) from the bare-earth points, which was used to identify any holes or gaps in the data coverage.
- Performed tile-by-tile analyses
  - Using TerraScan and LAS EQC, checked for gross errors in profile mode (noise, high and low points)
  - Reviewed each tile for anomalies; identified problem areas with a polygon, annotated comment, and screenshot as needed for clarification and illustration. Used ortho imagery when necessary to aid in making final determinations with regards to:
    - Buildings left in the bare-earth points file
    - Vegetation left in the bare-earth points file
    - Water points left in the bare-earth points file
    - Proper definition of roads
    - Bridges and large box culverts removed from the bare-earth points file
    - Areas that may have been "shaved off" or "over-smoothed" during the auto-filtering process
- Prepared and sent the error reports to LiDAR firm for correction
- Reviewed revisions and comments from the LiDAR firm
- Prepared and submitted final reports to FDEM

The LiDAR data of Okaloosa County was processed to a bare-earth terrain surface by Sanborn. The initial LiDAR dataset provided to URS for accuracy and qualitative assessment failed for three reasons: (1) systematic errors in vertical accuracy, (2) elevation offsets between flight lines and "cornrows" that exceeded the 20-cm criteria used by the LiDAR industry, and (3) excessive noise, artifacts and anomalies. The data was reprocessed and the revised dataset passed URS's qualitative assessment as reported at Appendix G.

Breakline Production Methodology

For the *hard breaklines*, Sanborn used GeoCue software to develop LiDAR stereo models for Okaloosa County. Using 3-D softcopy photogrammetric LiDARgrammetry procedures, and the LiDAR intensity imagery (stereo models), Sanborn stereo-compiled the eight types of *hard breaklines* in accordance with the Data Dictionary at Appendix C. The breaklines conform to data format requirements outlined by the FDEM Baseline Specifications.

For the *soft hydro breaklines*, Dewberry used 2.5-D techniques to digitize soft, linear hydrographic features first in 2-D and then used its GeoFIRM toolkit to drape the soft breaklines over the ESRI Terrain to derive the Z-values (elevations), also consistent with the Data Dictionary at Appendix C. All breakline compilation was performed under the direct supervision of an ASPRS Certified Photogrammetrist and Florida Professional Surveyor and Mapper (PSM). The breaklines conform with data format requirements outlined by the FDEM Baseline Specifications.

Whereas flowing rivers and streams are "hydro-enforced" to depict the downward flow of water, dry drainage features are not "hydro-enforced" but deliberately include undulations that more-accurately represent the true topography. This is, in fact, the ideal situation for topographic mapping.

The five figures below demonstrate how the PDS team's high LiDAR point density (4 points per square meter) are used to penetrate dense vegetation and accurately map the dry drainage feature not visible from a normal digital orthophoto (Figure 1); the total density of the LiDAR point cloud (Figure 2); the density of LAS Class 2 points that penetrated to the ground (Figure 3); the color-coded Terrain to help in visualizing the variable elevations (Figure 4); and the soft hydro breakline that approximates the potential flow line of the dry drainage feature and the contours that clearly show the undulations in the Terrain (Figure 5). At Figure 5, the 9-foot contour lines are *depression contours* that surround elevation points that are lower than 9-feet. Although the undulations, by definition, are not "hydro-enforced," the PDS Team's PSM in responsible charge of this project considers it a violation of professional standards if one were to deliberately degrade the accurate Terrain, soft hydro breakline and contours in a dry drainage feature in order to "hydro-enforce" that feature by filling the depressions and falsely scalping off the higher undulations in order to make an idealized monotonic dry streambed out of the true undulating streambed. To "hydro-enforce" such a dry streambed would be to falsify the true topography of naturally undulating terrain. The soft hydro breaklines are part of the hydrographic feature class, but have a separate sub-class code, 3. This enables hydro-enforced hydrographic features, sub-class codes 1 and 2 for single and dual lines, to be distinguished from these non-hydro-enforced soft hydrographic features representing dry drainage features.

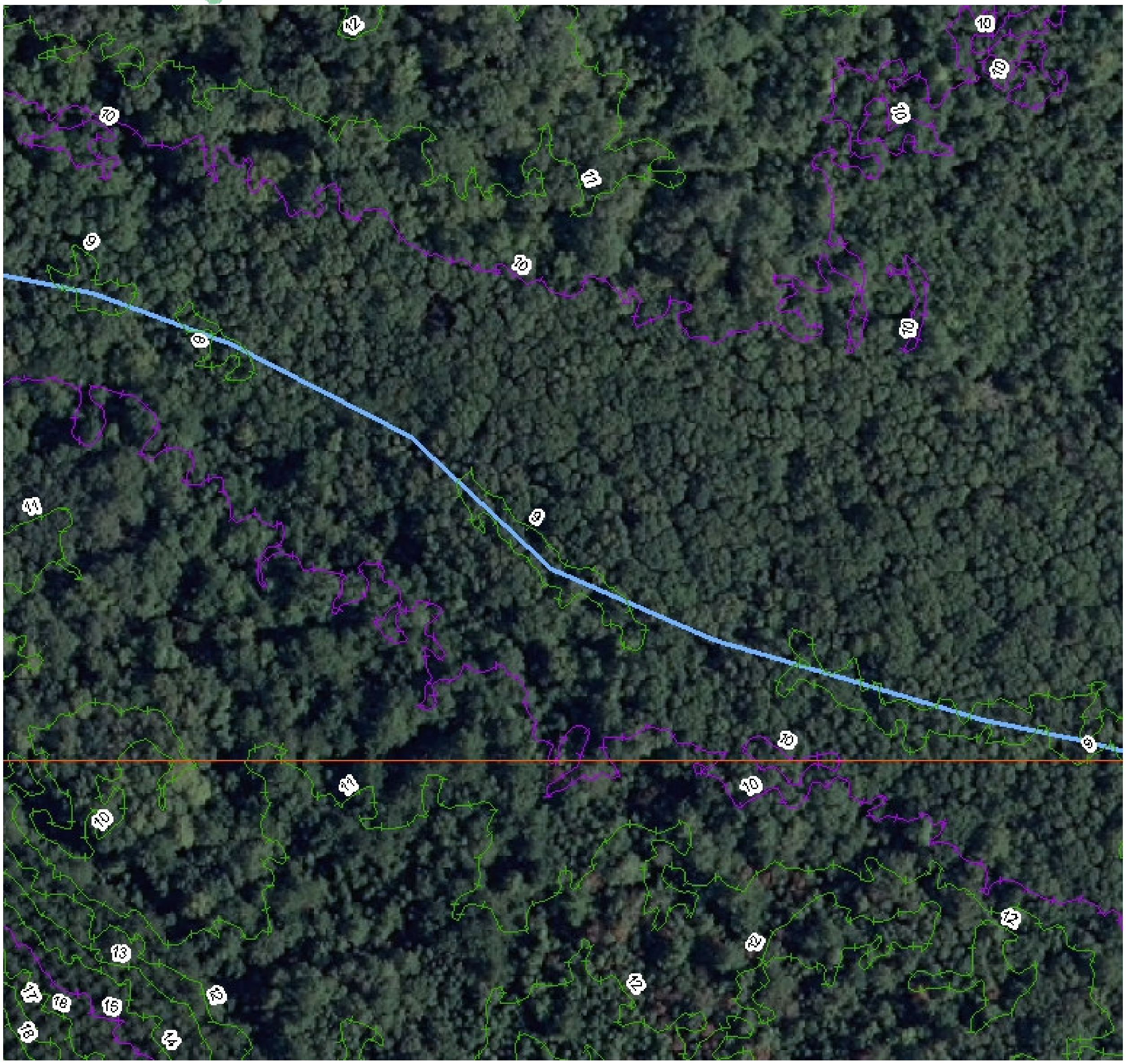


Figure 3. Even in very dense vegetation, the PDS team's high LiDAR point density (4 points per square meter) enabled the detection of dry drainage features beneath the vegetation.

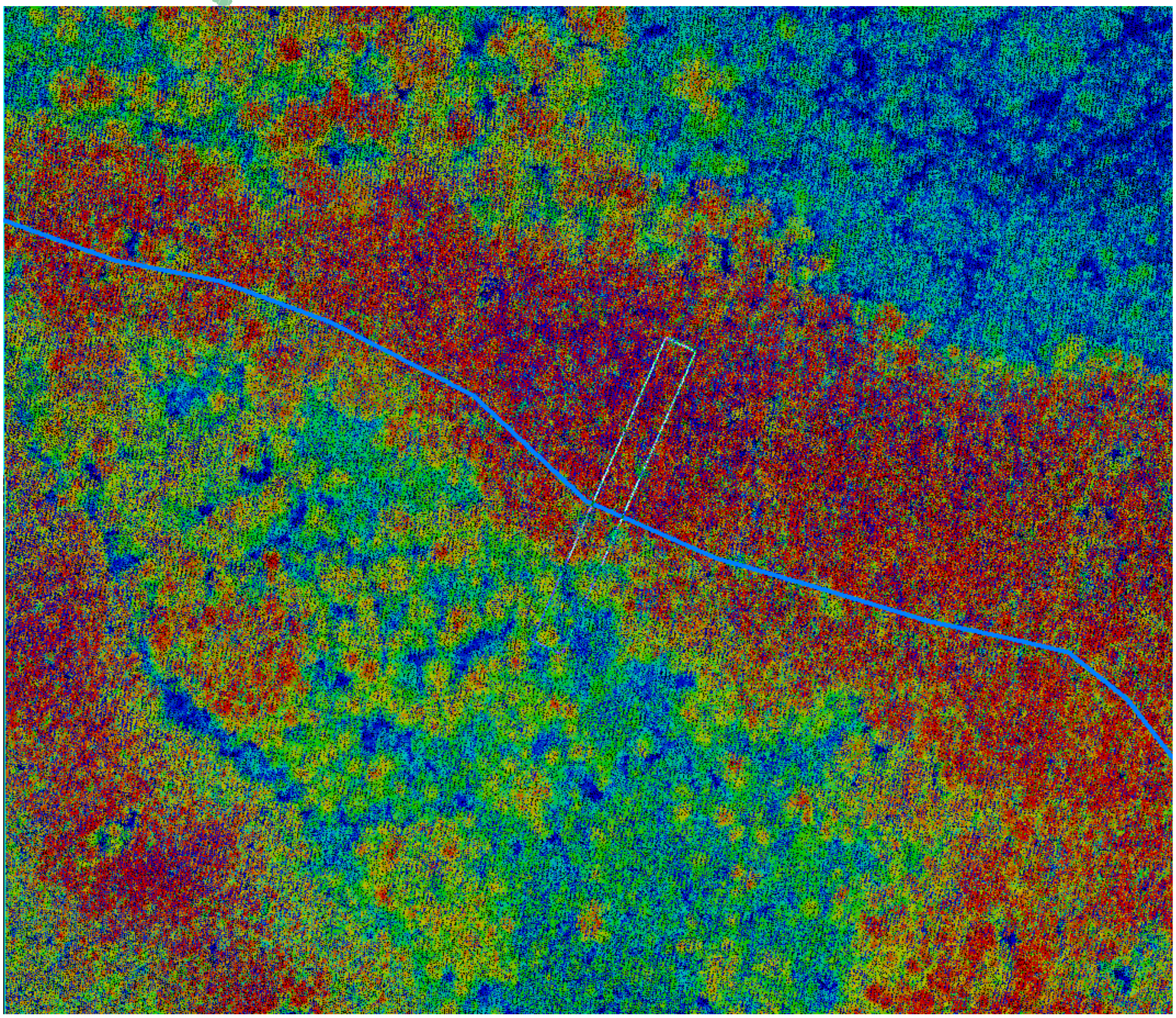
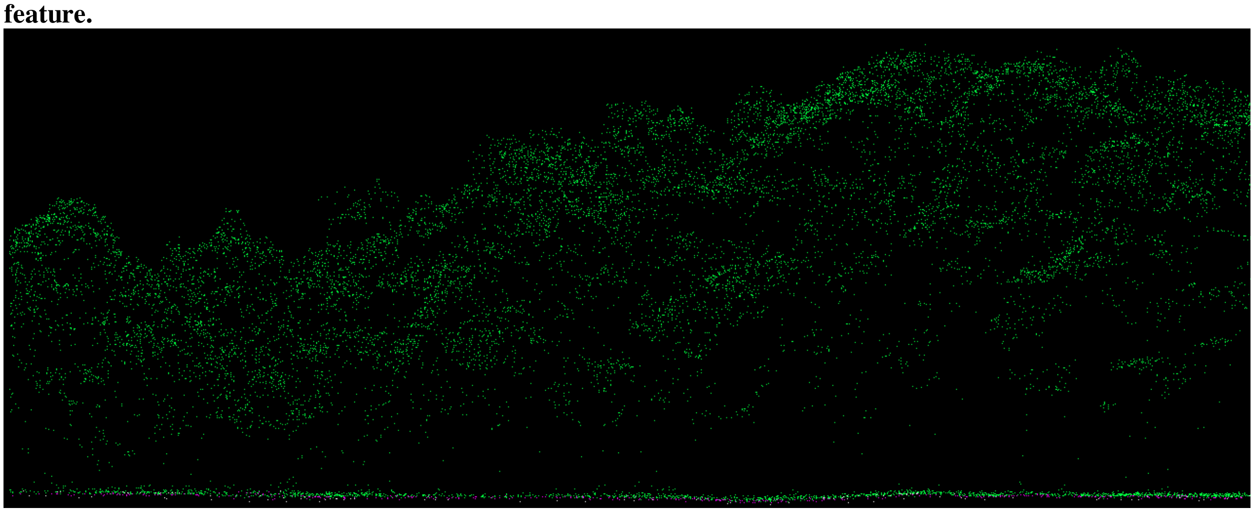


Figure 4. Full point cloud with profile (below) showing density of vegetation in the area of the dry drainage feature.



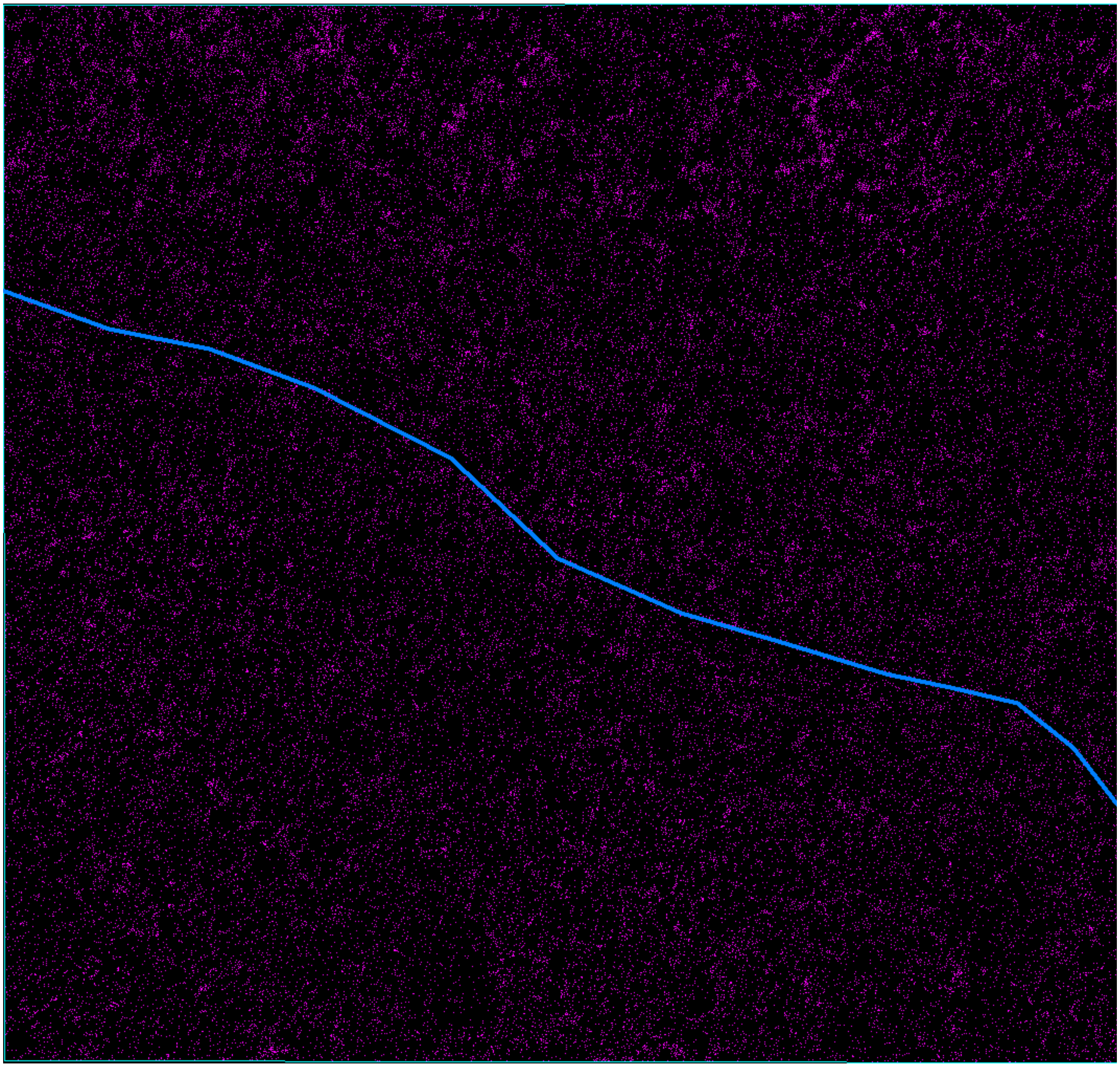


Figure 5. LAS Class 2 (ground) points showing the high density of points that penetrated the vegetation.

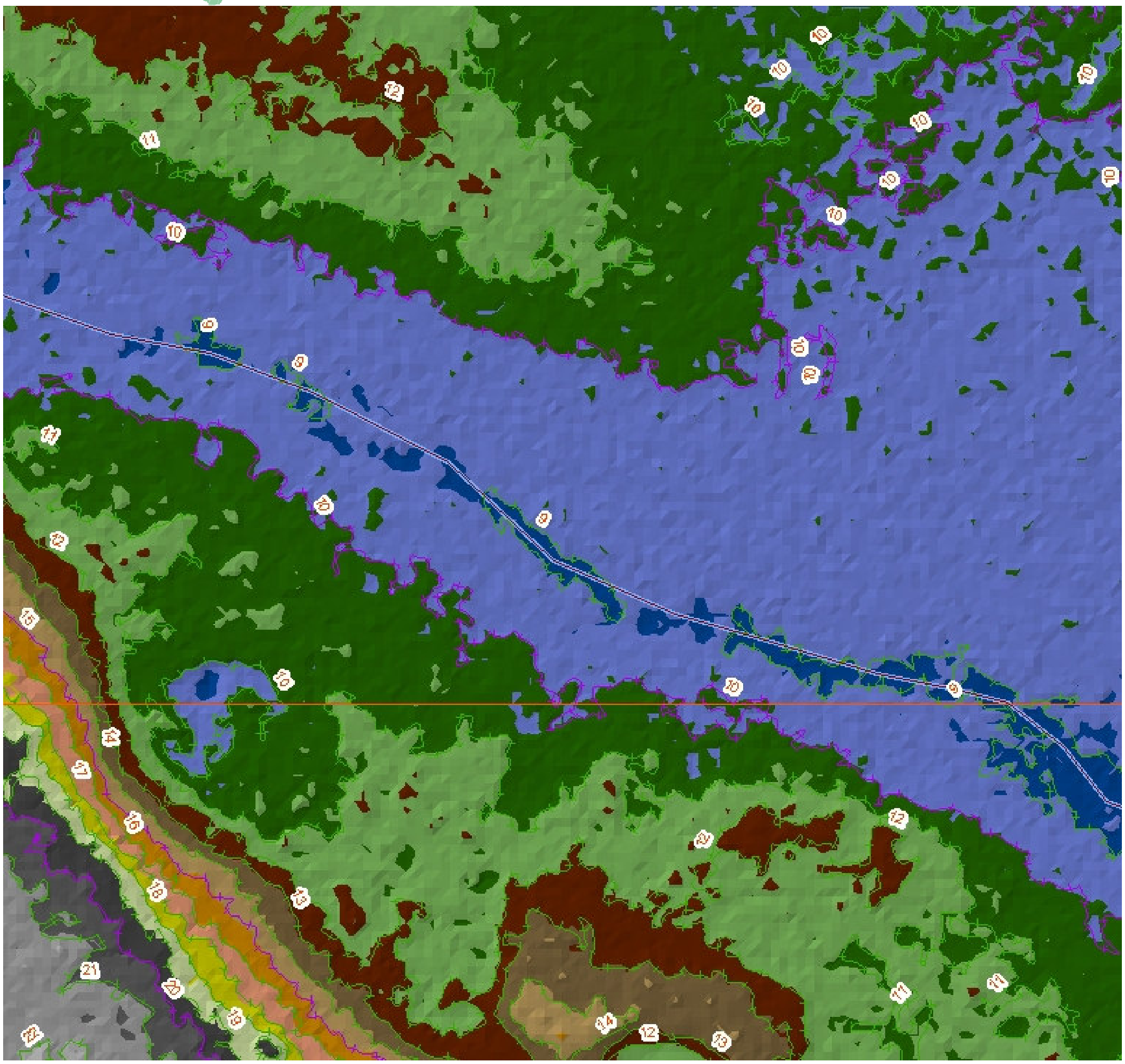


Figure 6. The ESRI Terrain is color-coded to depict the variable elevation bands. This clearly shows the lower, undulating elevations in the dry drainage feature.

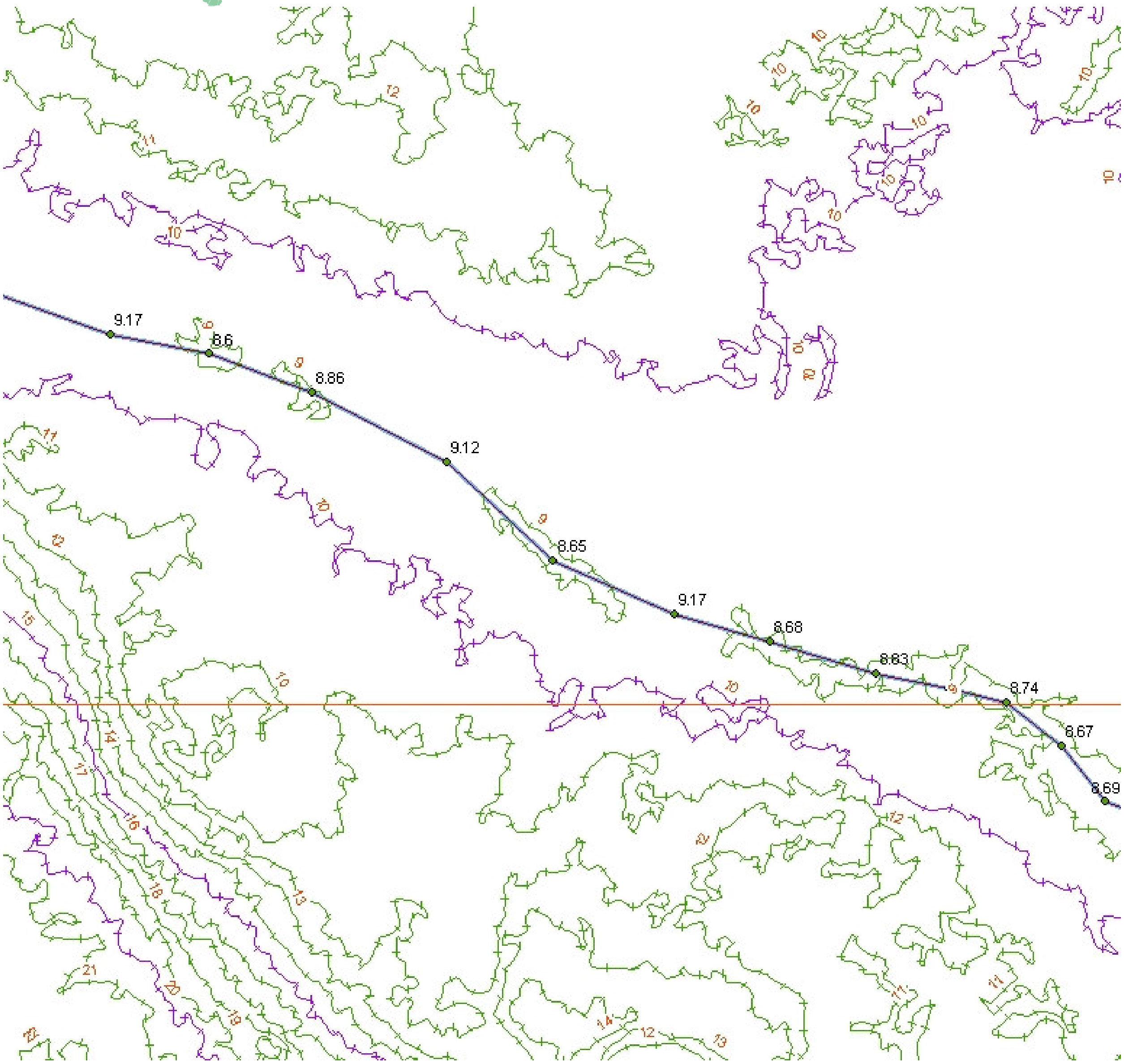


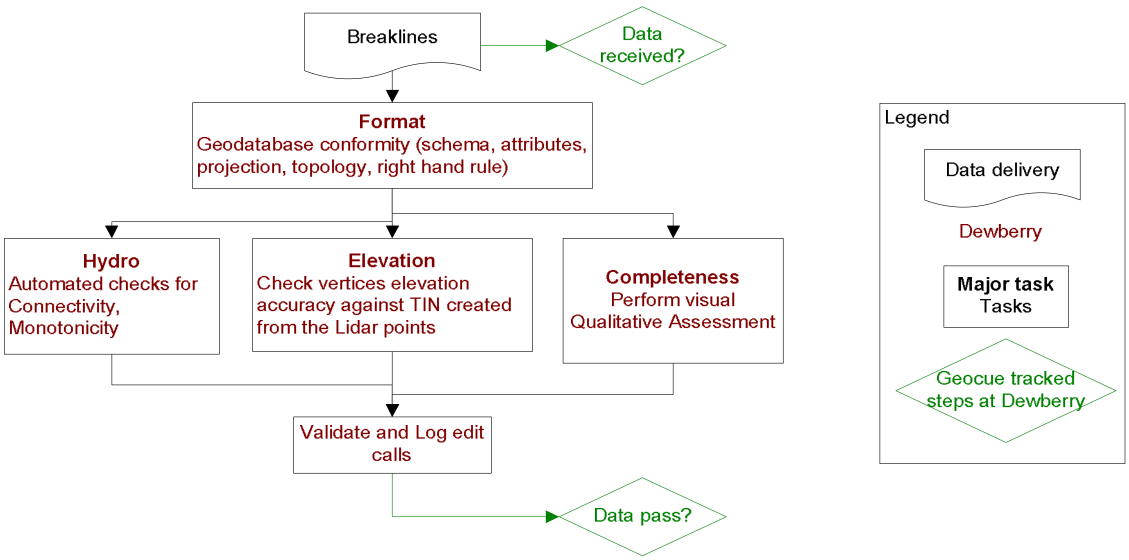
Figure 7. This figure shows variable "invert elevations" along the soft hydro breakline. It also shows "depression contours" where water would normally puddle if the drainage feature was only half dry. The soft hydro breakline passing through the "depression contours" clearly depict elevations lower than the 9-foot contour lines.

Contour Production Methodology

Sanborn used proprietary procedures to generate accurate contours from the LiDAR and breakline data. Using the LiDAR, a digital elevation model is filtered and further interpolated as a triangulated irregular network (TIN) of points. The TIN is rasterized to an ESRI GRID format and with the compiled breaklines, the 2-foot and 1-foot contours are generated and in accordance with the Data Dictionary at Appendix C. The contours conform to data format Requirements outlined by the FDEM Baseline Specifications.

Breakline Qualitative Assessments

Dewberry performed the breakline qualitative assessments. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.



In order to ensure a correct database format, Dewberry provided all subcontractors with geodatabase shells containing the required feature classes in the required format. Upon receipt of the data, Dewberry verified that the correct shell was used and validated the topology rules associated with it.

Feature Class	Rule	Feature Class
SOFTFEATURE	Must Not Intersect	
OVERPASS	Must Not Intersect	
ROADBREAKLINE	Must Not Intersect	
HYDROGRAPHIC...	Must Not Intersect	
SOFTFEATURE	Must Not Overlap With	ROADBREAKLINE
SOFTFEATURE	Must Not Overlap With	HYDROGRAPHICF
ROADBREAKLINE	Must Not Overlap With	HYDROGRAPHICF
SOFTFEATURE	Must Not Self-Intersect	
OVERPASS	Must Not Self-Intersect	
ROADBREAKLINE	Must Not Self-Intersect	
HYDROGRAPHIC...	Must Not Self-Intersect	

Figure 8. Breaklines topology rules

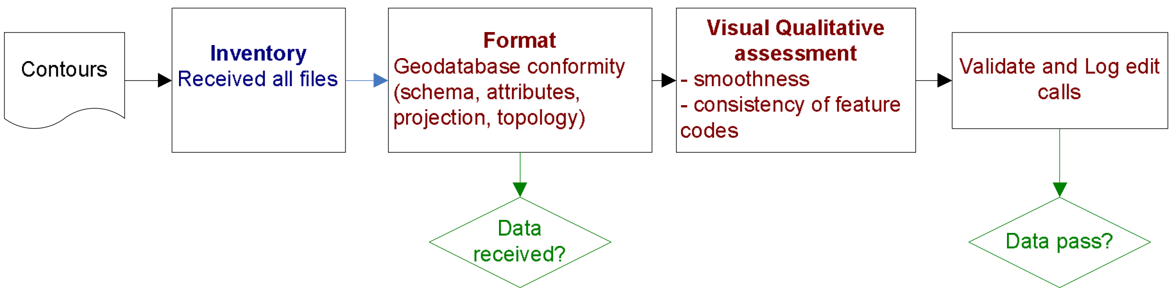
Then automated checks are applied on hydrofeatures to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the elevation extracted from the TIN built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations do not differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis of the breaklines. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations.

Contour Qualitative Assessments

Dewberry also performed the qualitative assessments of the contours using the following workflow.



Upon receipt of each delivery area, the first step performed by Dewberry was a series of data topology validations. Dewberry checked for the following instances in the data:

1. Contours must not overlap
2. Contours must not intersect
3. Contours must not have dangles (except at project boundary)
4. Contours must not self-overlap
5. Contours must not self-intersect

After the topology and geodatabase format validation was complete, Dewberry checked the elevation attribute of each contour to ensure NULL values are not included. Finally, Dewberry loaded the contour data plus the Lidar intensity images into ArcGIS and performed a full qualitative review of the contour data for smoothness and consistency of feature codes.

Appendix H summarizes Dewberry's qualitative assessments of the breaklines and contours, with graphic examples of what the breaklines and contours look like.

Deliverables

Except for the Report of Geodetic Control Survey for LiDAR and Photogrammetry, dated March 13, 2008, which was delivered separately and pertains to all deliverables in the Florida Panhandle, the deliverables listed at Table 5 are included on the external hard drive that accompanies this report.

Table 5. Summary of Deliverables

Copies	Deliverable Description	Format	Location
2	Report of Geodetic Control Survey for LiDAR and Photogrammetry, Northwest Florida, dated 3/13/2008	Hardcopy and pdf	Submitted separately
1	Data Dictionary	pdf	Appendix C

3	LiDAR Processing Report	Hardcopy and pdf	Appendix D
3	LiDAR Vertical Accuracy Report	Hardcopy and pdf	Appendix F
1	LiDAR Qualitative Assessment Report	pdf	Appendix G
1	Breakline/Contour Qualitative Assessment Report	pdf	Appendix H
1	Breaklines, Contours, Network-Adjusted Control Points, Vertical accuracy checkpoints, Tiling Footprint, Lidar ground masspoints	Geodatabase	Submitted separately

References

ASPRS, 2007, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

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Bureau of the Budget, 1947, *National Map Accuracy Standards*, Office of Management and Budget, Washington, D.C.

FDEM, 2006, Florida GIS, *Baseline Specifications for Orthophotography and LiDAR*, Appendix B, *Terrestrial LiDAR Specifications*, Florida Division of Emergency Management, Tallahassee, FL, October, 2006.

FEMA, 2004, Appendix A, *Guidance for Aerial Mapping and Surveying*, to “Guidelines and Specifications for Flood Hazard Mapping Partners,” Federal Emergency Management Agency, Washington, D.C.

FGCC, 1984, *Standards and Specifications for Geodetic Control Networks*, Federal Geodetic Control Committee, Silver Spring, ,MD, reprinted August 1993.

FGCC, 1988, *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques*, Federal Geodetic Control Committee, Silver Spring, MD, reprinted with corrections, August, 1989.

FGDC, 1998a, *Geospatial Positioning Accuracy Standards, Part I: Reporting Methodology*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/.

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 2, Standards for Geodetic Networks*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 3, National Standard for Spatial Data Accuracy*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998d, Content Standard for Digital Geospatial Metadata (CSDGM), Federal Geographic Data Committee, c/o USGS, Reston, VA, www.fgdc.gov/metadata/contstan.html.

NDEP, 2004, *Guidelines for Digital Elevation Data*, Version 1.0, National Digital Elevation Program, May 10, 2004, http://www.ndep.gov/

NOAA, 1997, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm),* NOAA Technical Memorandum NOS NGS-58, November, 1997.

General Notes

This report is incomplete without the external hard drives of the LiDAR masspoints, breaklines, contours, and control. See the Geodatabase structure at Appendix I.

This digital mapping data complies with the Federal Emergency Management Agency (FEMA) "Guidelines and Specifications for Flood Hazard Mapping Partners," Appendix A: *Guidance for Aerial Mapping and Surveying.*

The LiDAR vertical accuracy report at Appendix F conforms with the National Standard for Spatial Data Accuracy (NSSDA).

The digital mapping data is certified to conform to Appendix B, *Terrestrial LiDAR Specifications*, of the "Florida Baseline Specifications for Orthophotography and LiDAR." This report is certified to conform with Chapter 61G17-6, Minimum Technical Standards, of the Florida Administrative Code, as pertains to a Specific Purpose LiDAR Survey.

THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA PROFESSIONAL SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

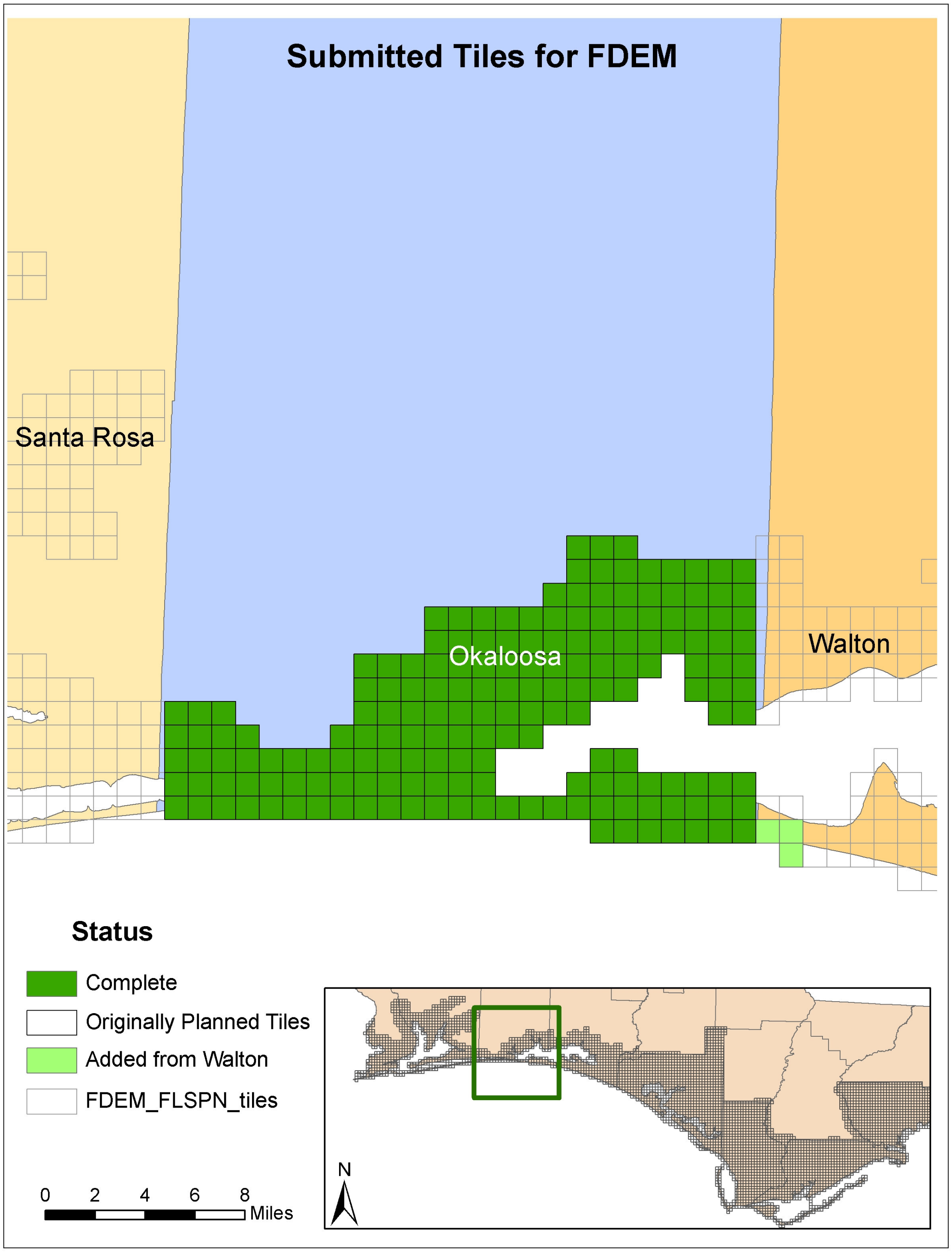
Surveyor and Mapper in Responsible Charge:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Professional Surveyor and Mapper
License #LS6659

Signed: ________________________________ Date: ________________

List of Appendices

A. County Project Tiling Footprint
B. County Geodetic Control Points
C. Data Dictionary
D. LiDAR Processing Report
E. QA/QC Checkpoints and Associated Discrepancies
F. LiDAR Vertical Accuracy Report
G. LiDAR Qualitative Assessment Report
H. Breakline/Contour Qualitative Assessment Report
I. Geodatabase Structure

Appendix A: County Project Tiling Footprint: Okaloosa



List of delivered complete tiles (180):

047060_N	047061_N	047062_N	047068_N	047069_N	044913_N	044914_N
044915_N	044916_N	044917_N	044918_N	044919_N	044920_N	048699_N
048700_N	048701_N	047070_N	047071_N	047072_N	047073_N	047074_N
047075_N	047076_N	047077_N	047083_N	047084_N	048702_N	048703_N
048704_N	044376_N	044377_N	044378_N	044379_N	044380_N	044381_N
044382_N	044383_N	044384_N	045988_N	045989_N	045990_N	045991_N
045992_N	044911_N	045993_N	045994_N	044912_N	044921_N	044922_N
044923_N	044924_N	045995_N	045996_N	045997_N	045998_N	045460_N
045461_N	045462_N	045463_N	045464_N	045999_N	046000_N	046002_N
046003_N	046004_N	048698_N	043297_N	043298_N	043299_N	043837_N
043838_N	043839_N	043840_N	043841_N	043842_N	043843_N	043844_N
050326_N	049783_N	049784_N	049785_N	049786_N	049226_N	049227_N
049228_N	049229_N	049230_N	049231_N	049232_N	049233_N	049234_N
049235_N	049236_N	049237_N	049238_N	049239_N	049240_N	049241_N
049242_N	049243_N	049244_N	047612_N	047613_N	047614_N	049778_N
049779_N	049780_N	049781_N	049782_N	047615_N	049220_N	049221_N
049222_N	049223_N	049224_N	049225_N	047600_N	047601_N	047602_N
047603_N	047607_N	047608_N	047609_N	047610_N	047611_N	048140_N
048141_N	045451_N	045452_N	045453_N	045454_N	045455_N	048147_N
045456_N	045457_N	045458_N	045459_N	048148_N	048149_N	048150_N
048151_N	048152_N	048153_N	048158_N	048159_N	048142_N	048143_N
048144_N	048145_N	048146_N	046528_N	046529_N	046530_N	046531_N
046532_N	046533_N	046534_N	046535_N	046536_N	046537_N	046538_N
046539_N	046542_N	046543_N	046544_N	048685_N	048686_N	048687_N
048688_N	048689_N	048690_N	048691_N	048692_N	048693_N	048697_N
048680_N	048681_N	048682_N	048683_N	048684_N		

List of delivered tiles in Okaloosa that were originally part of the Walton County delivery (3):

050326_N
049785_N
049786_N

Appendix B: Okaloosa County Geodetic Control Points

Station	County	Longitude	Latitude	Height (meters)	Ellipsoid Height	Description
BG2048	Okaloosa	86 34 7.26370	30 27 33.24357	12.701	-14.611	RECOVERED NSRS STATION (SEE DATASHEET PID# BG2048)
BG4869	Okaloosa	86 28 4.90364	30 23 43.52788	5.359	-21.969	RECOVERED NSRS STATION (SEE DATASHEET PID# BG4869)
BG5051	Okaloosa	86 44 25.34777	30 24 42.60508	5.38	-21.868	RECOVERED NSRS STATION (SEE DATASHEET PID# BG5051)
BG2048	Okaloosa	86 34 7.26370	30 27 33.24357	12.701	-14.611	RECOVERED NSRS STATION (SEE DATASHEET PID# BG2048)
BG4869	Okaloosa	86 28 4.90364	30 23 43.52788	5.359	-21.969	RECOVERED NSRS STATION (SEE DATASHEET PID# BG4869)
BG5051	Okaloosa	86 44 25.34777	30 24 42.60508	5.38	-21.868	RECOVERED NSRS STATION (SEE DATASHEET PID# BG5051)
FB173P07	Okaloosa	86 23 50.98847	30 23 7.83541	5.173	-22.196	SET SECONDARY MONUMENT
FB173P12	Okaloosa	86 36 45.34065	30 25 0.88615	4.053	-23.222	SET SECONDARY MONUMENT
FB173P13	Okaloosa	86 25 33.03247	30 29 25.27478	15.095	-12.287	SET SECONDARY MONUMENT

Appendix C: Data Dictionary

LiDARgrammetry Data Dictionary & Stereo Compilation Rules

FINAL

FDEM (Florida Department of Emergency Management)

January 25, 2008

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Horizontal and Vertical Datum

Horizontal datum shall be referenced to the appropriate Florida State Plane Coordinate System. The horizontal datum shall be North American Datum of 1983/HARN adjustment in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). Geoid03 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to the appropriate Florida State Plane Coordinate System Zone, Units in US Survey Feet.

Contour Topology Rules

The following contour topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: CONTOURS_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
CONTOUR_1FT	5	1	1	No
CONTOUR_2FT	5	1	1	No

Topology Rules

Name	**Rule Type**	**Trigger Event**	**Origin** (*FeatureClass::Subtype*)	**Destination** (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All

Breakline Topology Rules

The following breakline topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
OVERPASS	5	1	1	No
ROADBREAKLINE	5	1	1	No
SOFTFEATURE	5	1	1	No

Topology Rules

Name	**Rule Type**	**Trigger Event**	**Origin** (*FeatureClass::Subtype*)	**Destination** (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	OVERPASS::All	OVERPASS::All
Must not intersect	The rule is a line-no intersection rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	ROADBREAKLINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	OVERPASS::All	OVERPASS::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Coastal Shoreline

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: COASTALSHORELINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will outline the land / water interface at the time of LiDAR acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Coast	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Coastal Shoreline	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may require some feathering or edge matching to ensure a smooth transition. Orthophotography will not be use to delineate this shoreline.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. For the polygon closure vertices and segments, null values or a value of 0 are acceptable since this is not an actual shoreline. The digital orthophotography is not a suitable source for capturing this feature. Efforts should be taken to gradually feather the difference between tidal conditions of neighboring flights. Stair-stepping of the breakline feature will not be allowed. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water

			where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Linear Hydrographic Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: HYDROGRAPHICFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict linear hydrographic features with a length of 0.5 miles or longer as breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	HydroL	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Single Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, embankments, etc. with an average width less than or equal to 8 feet. . In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line. Each vertex placed should maintain vertical integrity.
2	Dual Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, etc. with an average width greater than 8 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class.	Capture features showing dual line (one on each side of the feature). Average width shall be great than 8 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is not required to show “closed polygon”. These instructions are only for docks or piers that follow

			the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.
3	Soft Hydro Single Line Feature	Linear hydro features with an average width less than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line.
4	Soft Hydro Dual Line Feature	Linear hydro features with an average width greater than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 8 feet to show as a double line. Data is not required to show "closed polygon".

Note: Carry through bridges for all linear hydrographic features.

Closed Water Body Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: WATERBODY
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict closed water body features and will have the associated water elevation available as an attribute.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
WATERBODY_ELEVATION_MS	Double	Yes			0	0		Assigned by PDS
TYPE	Long Integer	No	1	HydroP	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Water Body	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features one-half acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> The field "WATERBODY_ELEVATION_MS" shall be automatically computed from the z-value of the vertices. An Island within a Closed Water Body Feature will also have a "donut polygon" compiled in addition to an Island polygon. These instructions are only for docks or piers that follow

			the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Road Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ROADBREAKLINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict apparent edge or road pavement as breaklines but will not include bridges or overpasses.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Road	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Edge of Pavement	Capture edge of pavement (non-paved or compact surfaces as open to compiler interpretability) on both sides of the road. Runways are not to be included.	DO NOT INCLUDE Bridges or Overpasses within this feature type. Capture apparent edge of pavement (including paved shoulders). Each vertex placed should maintain vertical integrity and data is not required to show "closed polygon". Box culverts should be continued as edge of pavement unless a clear guardrail system is in place; in that case, feature should be shown as bridge / overpass.

Bridge and Overpass Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: OVERPASS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict bridges and overpasses as separate entities from the edge of pavement feature class.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Bridge	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bridge Overpass	Feature should show edge of bridge or overpass.	Capture apparent edge of pavement on bridges or overpasses. Do not capture guard rails or non-drivable surfaces such as sidewalks. Capture edge of drivable pavement only. Each vertex placed should maintain vertical integrity and data is not required to show “closed polygon”. Box culverts should be captured in this feature class if a clear guardrail system is in place; otherwise, show as edge-of-pavement.

Soft Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: SOFTFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict soft changes in the terrain to support better hydrological modeling of the LiDAR data and sub-sequent contours.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Soft	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Soft Breakline	Supplemental breaklines where LiDAR mass points are not sufficient to create a hydrologically correct DTM. Soft features shall include ridges, valleys, top of banks, etc. Soft features may also include natural Embankments that act as small ponding areas. Top of Banks can also be included in the soft breakline class so long as it does not define the edge of a water feature.	Capture breaklines to depict soft changes in the elevation. If the elevation changes are easily visible, go light on the breakline capture. Each vertex placed should maintain vertical integrity.

Island Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ISLAND
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict natural and man-made islands as closed polygons.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Island	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Island	Apparent boundary of natural or man-made island feature captured with a constant elevation. Island features will be captured for features one-half acres in size or greater.	Island shall take precedence over Coastal Shore Line Features. Islands shall be captured as closed polygons with the land feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed around the island. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated

			headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Low Confidence Areas

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONFIDENCE
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation meaning that the resultant contours may not meet the required accuracy specifications.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	Apparent boundary of vegetated areas that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. These features are for reference only to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.	Capture as closed polygon with the obscured area to the right of the line. Compiler does not need to worry about z-values of vertices; feature class will be 2-D only.

Note: Area must be ½ acre or larger. Only outline areas where you are not sure about vegetative penetration of the LiDAR data. This is not the same as a traditional obscured area.

Masspoints

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: MASSPOINT
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts masspoints as determined by the LiDAR ground points (LAS Class 2).

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Masspoint	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Masspoint	Only the bare earth classification (Class 2) shall be loaded into the MASSPOINT feature class.	None. Data should be loaded from LAS Class 2 (Ground)

1 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_1FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1' contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between. If the horizontal distance between two adjacent contours is

		unduly prominent on the published map.	larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5^{th} contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

2 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_2FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1' contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between.

		shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map.	If the horizontal distance between two adjacent contours is larger than 1” at map scale (100’), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200’.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

Ground Control

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: GROUNDCONTROL
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used in the acquisition and calibration of the LiDAR and aerial photography collected by Aero-Metric, Sanborn and Terrapoint.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Control	0	0		Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Control Point	Primary or Secondary PDS control points used for either base station operations or in the calibration and adjustment of the control.	None.

Vertical Accuracy Test Points

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: VERTACCTESTPTS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used by PDS to test the vertical accuracy of the data produced.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS
LANDCOVER	Long Integer	No	1	dLANDCOVERTYPE	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bare-Earth and Low Grass	None.	None.
2	Brush Lands and Low Trees	None.	None.
3	Forested Areas Fully Covered by Trees	None.	None.
4	Urban Areas	None.	None.

Footprint (Tile Boundaries)

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: FOOTPRINT
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class includes the Florida 5,000' x 5,000' tiles for each countywide geodatabase produced.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
CELLNUM	String	No			0	0	8	Assigned by PDS

Contact Information

Any questions regarding this document should be addressed to:

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Appendix D: LiDAR Processing Report

Dewberry
LiDAR Campaign
Final Report
For
FDEM – Okaloosa County
March 2008

Prepared by:

Sanborn

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Phone: (719) 593-0093

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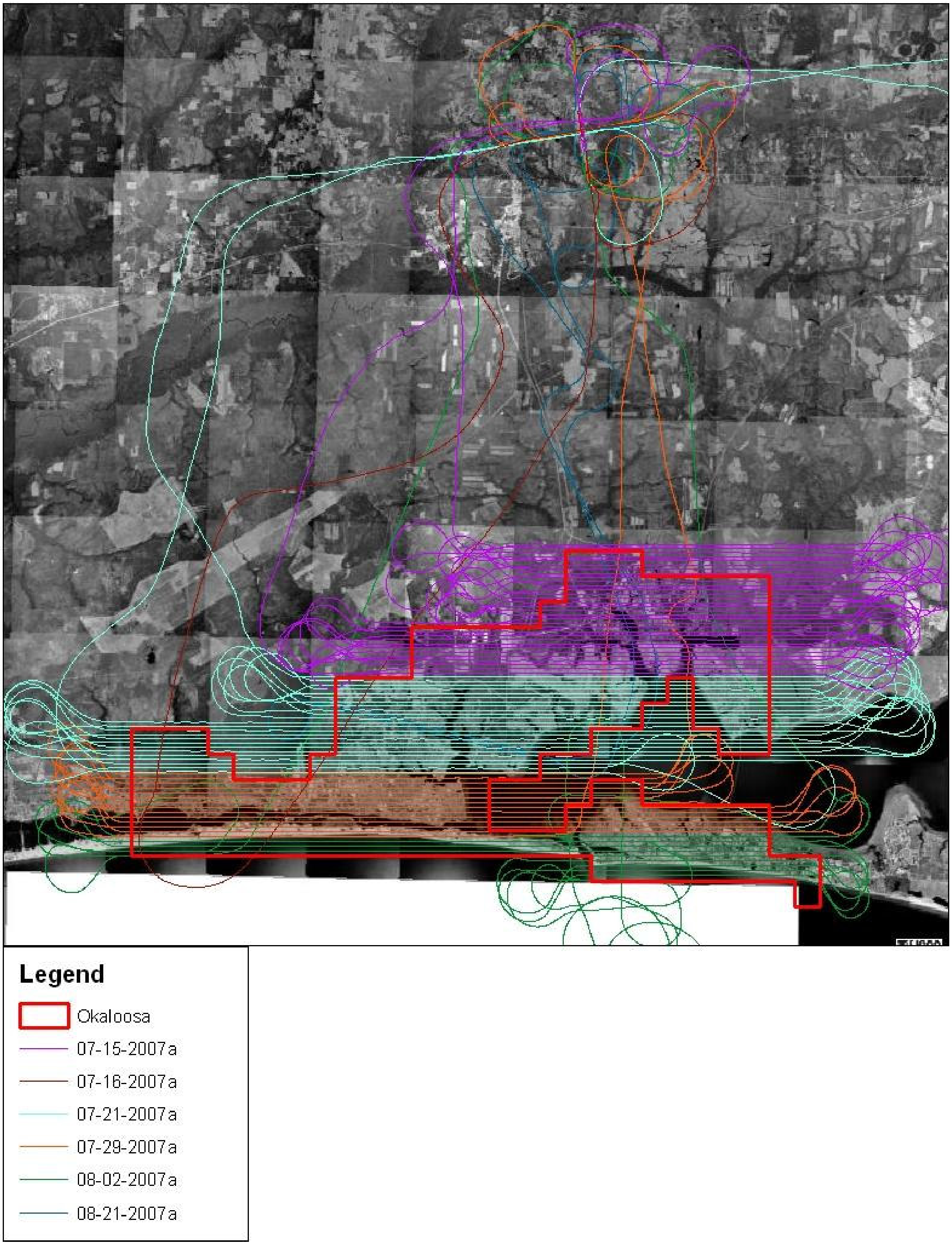
EXECUTIVE SUMMARY

In the spring of 2007, Sanborn was contracted by Dewberry to execute a LiDAR (Light Detection and Ranging) survey campaign in the state of Florida. LiDAR data in the form of 3-dimensional positions of a dense set of mass points was collected for the 167 square miles of Okaloosa County. This data was used in the development of the bare-earth-classified elevation point data sets.

The Leica ALS-50 LiDAR system and the Optech ALTM 2050 LiDAR system was used to collect data for the Okaloosa County survey campaign, per the flight line map shown on the next page. The LiDAR system is calibrated by conducting flight passes over a known ground surface before and after each LiDAR mission. During final data processing, the calibration parameters are inserted into post-processing software.

The acquired LiDAR data was processed to obtain first and last return point data. The last return data was further filtered to yield a LiDAR surface representing the bare earth.

The contents of this report summarize the methods used to establish the base station coordinate check, perform the LiDAR data collection and post-processing as well as the results of these methods.


Legend
Okaloosa
07-15-2007a
07-16-2007a
07-21-2007a
07-29-2007a
08-02-2007a
08-21-2007a

INTRODUCTION

This report contains the technical write-up of the Dewberry LiDAR campaign, including system calibration techniques, the establishment of base stations by a differential GPS network survey, and the collection and post-processing of the LiDAR data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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Attention: -------- Andy Lucero (Project Manager)
------ Jamie Young (LiDAR General Manager)
Telephone: ------- 1–719-264-5602
FAX: ---------------- 1–719-264-5637
email: --------------- jyoung@sanborn.com

1.2 Purpose of the LiDAR Acquisition

This LiDAR operation was designed to provide a highly detailed ground surface dataset to be used for the development of topographic, contour mapping and hydraulic modeling

1.3 Project Location

Okaloosa County, Florida

1.4 Project Scope, Specifications and Time Line

The summer of 2007 LiDAR Flight Acquisition required the collection of 167 square miles of Okaloosa County collected at a nominal point spacing of 0.7 meters and based on the Sanborn FEMA compliant LiDAR product specification.

Table 1: Project Specifications and Deliverable Coordinate and Datum Systems

Area (sq. mi)	167	**Product type**	Fema(F)	**Projection**	Florida State Plane
Vertical RMSE (CM)	Bare Earth 9.25cm	**Check Points required**	Yes	**Horizontal Datum Vertical Datum**	NAD83/Harn NAVD88
Horizontal RMSE (CM)	50cm	**Number Collected**	60	**Units**	US Survey Ft

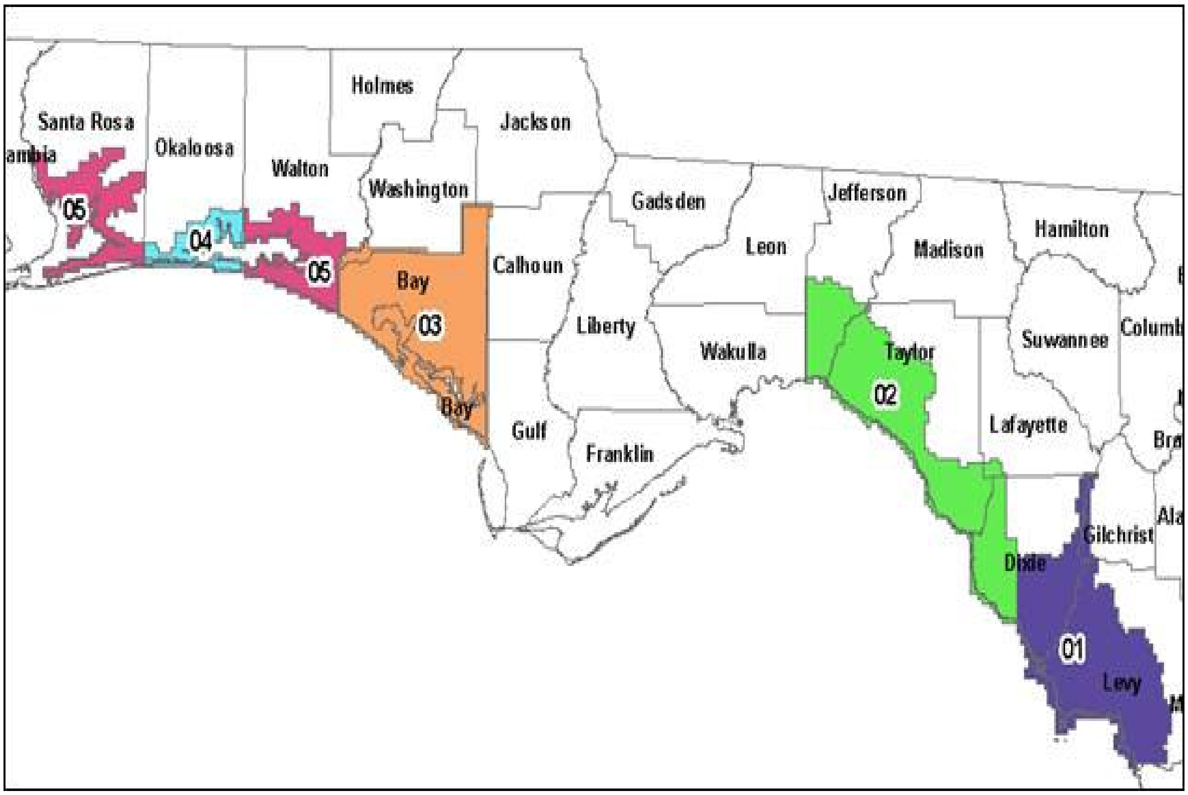

Figure 1: Area of Collection
(The area displayed in light blue is Okaloosa)

LiDAR CALIBRATION

2.1 Introduction

LiDAR calibrations are performed to determine and therefore eliminate systematic biases that occur within the hardware of the Leica ALS-50 system and the Optech ALTM 2050 system. Once the biases are determined they can be modeled out. The systematic biases are corrected for include scale, roll, and pitch.

The following procedures are intended to prevent operational errors in the field and office work, and are designed to detect inconsistencies. The emphasis is not only on the quality control (QC) aspects, but also on the documentation, i.e., on the quality assurance (QA).

2.2 Calibration Procedures

Sanborn performs two types of calibrations on its LiDAR system. The first is a building calibration, and it is done any time the LiDAR system has been moved from one plane to another. New calibration parameters are computed and compared with previous calibration runs. If there is any change, the new values are updated internally or during the LiDAR post-processing. These values are applied to all data collected with the plane/ALS-50/ALTM 2050 system configurations.

Once final processing calibration parameters are established from the building data, a precisely-surveyed surface is observed with the LiDAR system to check for stability in the system. This is done several times during each mission. An average of the systematic biases are applied on a per mission basis.

2.3 Building Calibration

Whenever the ALS-50 or ALTM 2050 is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building is surveyed on the ground using conventional survey methods, and used as the LiDAR calibration target. The aircraft flies several specified passes over the building with the ALS-50 system and the ALTM 2050 system set first in scan mode, then in profile mode, and finally in both scan and profile modes with the scan angle set to zero degrees.

Figure 2 shows a pass over the center of the building. The purpose of this pass is to identify a systematic bias in the scale of the system.

Figure 3 demonstrates a pass along a distinct edge of the building to verify the roll compensation performed by the Inertial Navigation System, INS.

Additionally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.

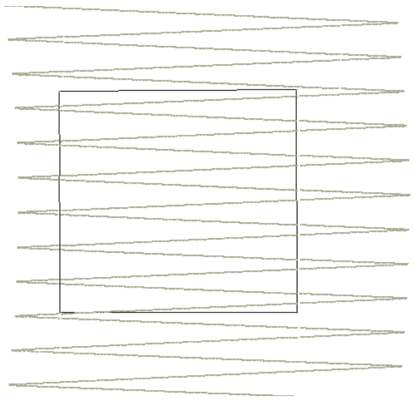

Figure 2: Calibration Pass 1

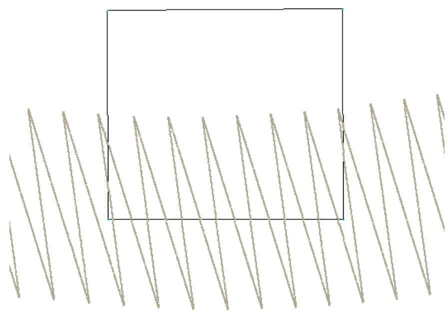

Figure 3: Calibration Pass 2

2.4 Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Bob Sikes Airport for Okaloosa County using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway surface. The LiDAR system is flown at right angles over the runway several times and residuals are generated from the processed data. Figure 4 shows a typical pass over the runway surface.

Approximately 25,000 LiDAR points are observed with each pass. A Triangulated Irregular Network (TIN) surface is created from these passes. The ground control x,y,z points are then compared with the z of the LiDAR surface to compute vertical residuals of the LiDAR data. After careful analysis of noise associated with non-runway returns, any system bias is documented and removed from the process.

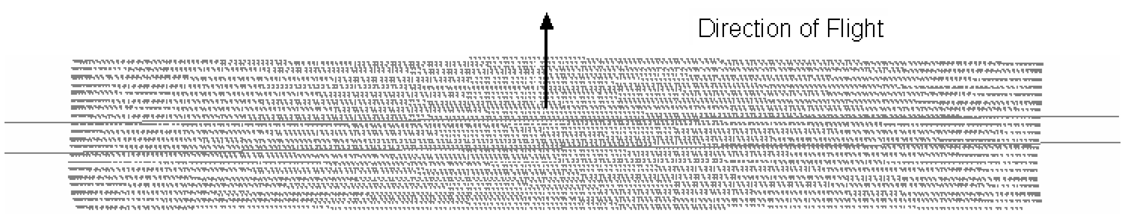

Figure 4: Runway Calibration

3 RUNWAY CALIBRATION, SYSTEM PERFORMANCE VALIDATION

3.1 Calibration Results

"Bore-sighting" and "runway calibration" are essentially the same thing, i.e., they determine if the LiDAR sensor has maintained its factory calibration and is still sensing the correct position on the ground, both vertically and horizontally. The LiDAR data captured over the building is used to determine whether there have been any changes to the alignment of the Inertial Measurement Unit, IMU, with respect to the laser system. The parameters are designed to eliminate systematic biases within certain system parameters.

The runway over-flights are intended to be a quality check on the calibration and to identify any system irregularities and the overall noise. IMU misalignments and internal system calibration parameters are verified by comparing the collected LiDAR points with the runway surface.

Figure 5 shows the typical results of a runway over-flight analysis. The X-axis represents the position along the runway. The overall statistics from this analysis provides evidence of the overall random noise in the data (typically, 7 cm standard deviation – an unbiased estimator, and 8 cm RMS which includes any biases) and indicates that the system is performing within specifications. As described in later sections of this report, this analysis will identify any peculiarities within the data along with mirror-angle scale errors (identified as a "smile" or "frown" in the data band) or roll biases.

> The calibration is done based on a kinematic survey on the runway. Given that the Kinematic survey RMSE is no better than 4 centimeters as a result of non- exact height of the antenna and weight of the aircraft. Sanborn was required to do additional check points in the project area to meet the 9.25 centimeter vertical accuracy requirement knowing that the calibration site is only good to 4 centimeters RMSE. A z bump adjustment was made to the entire data set based on the survey points in the project area and the relative accuracy of the data to itself and in all areas.

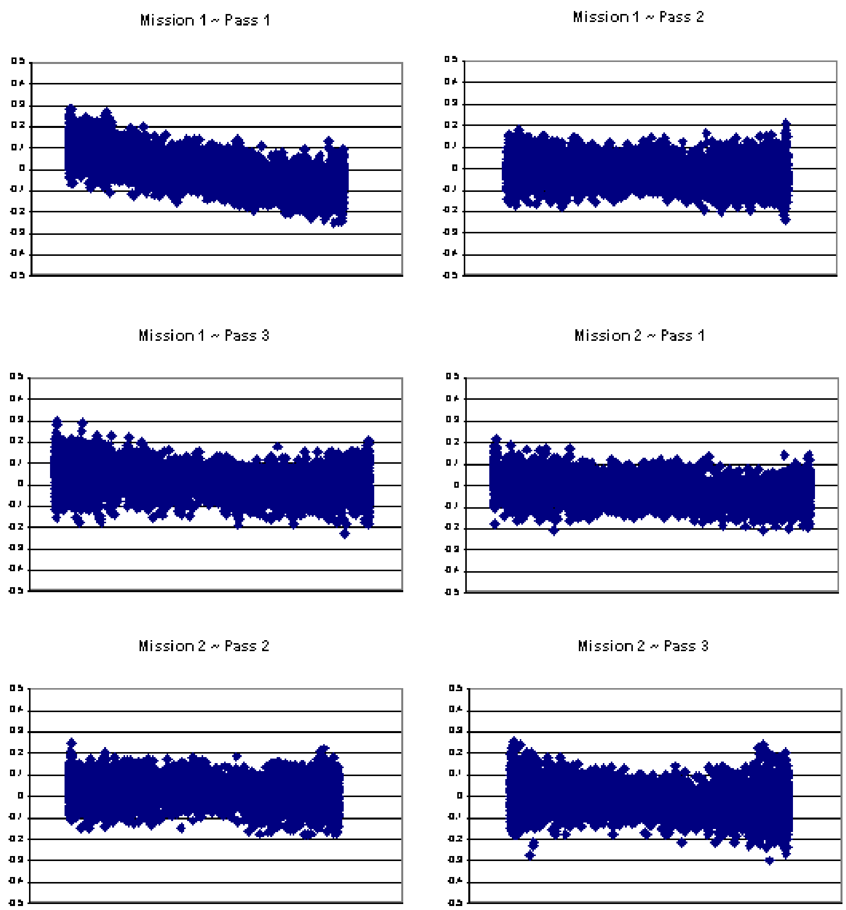

Figure 5: Runway Calibration Results

3.2 Daily Runway Performance/Data Validation Tests

Performance flights over the runway test field were performed before and after each mission. Table 2 shows the standard deviation and RMS values of the residuals between the test flights and the known surface of the test ranges for each pass. The maximum RMS value is 0.086 meters and the maximum standard deviation is 0.073 meters. The average RMS among all test flights is 0.068 meters.

Table 2: Runway Validation Results for Okaloosa County (Meters)

Mission	Passes	Standard Deviation	RMS
196a_LMSI	2	0.073	0.073
210a_Leica	4	0.037	0.047
214a_Leica	4	0.039	0.064
233a_Leica	4	0.061	0.086

3.3 Horizontal Validation

The horizontal accuracy was checked within the calibration site and the project area. Five random tiles within each county were selected and five calibrations within each county were selected for the different missions. The horizontal accuracy was checked at both center and edge of the flight line swath in the calibration lines. In the project area the horizontal accuracy was checked in the overlapping areas of these tiles. Locations for each check was randomly selected based on like features in a single flightline overlap or corresponding calibration lines. For example, building corner locations were identified and differences where measured in reference to each other. Given that the calibration lines were flown in opposing directions and an additional line was flown perpendicular to these opposing lines, this would indicate a valid horizontal position to the absolute location of the position. If there was an error greater than stated in the specifications, the location directional misalignment would be greater than the specified RMSE in either northing or easting. The difference was checked and the RMSE of all differences were computed and reported in Tables 3 & 4 below. Based on the results of Table 3 & 4 it has been determined that the horizontal accuracy has been met. $RMSE_r = SQRT (RMSE_x^2 + RMSE_y^2) = 40.058$ cm = 1.314 ft. Horizontal accuracy at the 95% confidence level = $RMSE_r \times 1.7308 = 2.274$ ft, well within the 3.8 ft horizontal accuracy specification.

Table 3: Horizontal Validation Results for Okaloosa County (Centimeters)

Okaloosa County			
Tile	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
48140	36.79	24.81	C
48682	27.44	39.54	C
48146	47.42	37.45	E
47608	29.74	31.41	E
46529	34.62	33.93	C
RMSE	**35.202**	**33.428**	
Calibration Mission	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
Day210	14.35	10.26	C
Day214	26.01	26.52	C
Day233	14.78	18.05	C
RMSE	**18.380**	**18.276**	

Table 4: Combined Horizontal Validation Results for Okaloosa County (Centimeters)

Tile/Mission	Northing (cm)	Easting (cm)	Center/Edge
48140	36.79	24.81	C
48682	27.44	39.54	C
48146	47.42	37.45	E
47608	29.74	31.41	E
46529	34.62	33.93	C
Day210	14.35	10.26	C
Day214	26.01	26.52	C
Day233	14.78	18.05	C
RMSE	**28.893**	**27.746**	

4 LiDAR FLIGHT AND SYSTEM REPORT

4.1 Introduction

This section addresses LiDAR system, flight reporting and data acquisition methodology used during the collection of the Okaloosa County campaign. Although Sanborn conducts all LiDAR with the same rigorous and strict procedures and processes, all LiDAR collections are unique.

4.2 Field Work Procedures

A minimum of two GPS base stations were set up, with one receiver located at the airport set up on BG5100, and the secondary GPS receivers placed at the survey control points BG2048 and BG4869, which are within the project area or within the required baseline specifications of the project.

Pre-flight checks such as cleaning the sensor head glass are performed. A four minute INS initialization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations.

The flight missions were typically four or five hours in duration including runway calibration flights flown at the beginning and the end of each mission. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission GPS ambiguities are again resolved by flying within ten kilometers of the base stations, to aid in post-processing.

Table 5 and 6 shows the planned Leica acquisition parameters for Sanborn with a flying height of 800 meters above ground level (AGL) on a mission to mission basis. And the planned Optech acquisition parameters for LMSI, which has a height of 700 meters above ground level (AGL) on a mission to mission basis.

Table 5: LiDAR Sanborn Leica Acquisition Parameters

Average Altitude	800 Meters AGL
Airspeed	~120 Knots
Scan Frequency	36 Hertz
Scan Width Half Angle	20 Degrees
Pulse Rate	50,000 Hertz

Table 6: LiDAR LMSI Optech Acquisition Parameters

Average Altitude	700 Meters AGL
Airspeed	~110 Knots
Scan Frequency	49 Hertz
Scan Width Half Angle	20 Degrees
Pulse Rate	70,000 Hertz

Preliminary data processing was performed in the field immediately following the missions for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs office.

Table 7: Collection Dates, Times, Average Per Flight Collection Parameters and PDOP

Mission	Date	Sensor / Sub	Start Time	End Time	Altitude (m)	Airspeed (Knots)	Scan Angle	Scan Rate	Pulse Rate	PDOP
196a	Jul 15	LMSI	15:52	21:46	700	110	40˚	49	70000	1.8
202a	Jul 21	LMSI	16:15	21:45	700	110	40˚	49	70000	1.7
210a	Jul 29	Leica	23:05	2:51	800	120	40˚	36	50000	1.2
214a	Aug 2	Leica	12:31	4:41	800	120	40˚	36	50000	1.0
233a	Aug 21	Leica	22:09	22:56	800	120	40˚	36	50000	1.1

4.3 Final LiDAR Processing

Final post-processing of LiDAR data involves several steps. The airborne GPS data was post-processed using Waypoint's GravNAV^{TM} software (version 7.5). A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. The data was processed for both base stations and combined. In the event that the solution worsened as a result of the combination of both solutions the best of both solutions was used to yield more accurate data. LiDAR acquisition was limited to periods when the PDOP was less than 3.2.

The GPS trajectory was combined with the raw IMU data and post-processed using Applanix Inc.'s POSPROC (version 4.3) Kalman Filtering software. This results in a two-fold improvement in the attitude accuracies over the real-time INS data. The best estimated trajectory (BET) and refined attitude data are then re-introduced into the LEICA ALS post processor for the Leica system and the REALM Survey Suite OPTECH for the Optech system to compute the laser point-positions. The trajectory is then combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

All return values are produced within ALS Post processing software for the Leica system and within REALM Survey Suite OPTECH software for the Optech system. The multireturn information is processed to obtain the “Bare Earth Dataset” as a deliverable. All LiDAR data is processed using the binary LAS format 1.1 file format.

LiDAR filtering was accomplished using TerraSolid, TerraScan LiDAR processing and modeling software. The filtering process reclassifies all the data into classes with in the LAS formatted file based scheme set using the LAS format 1.1 specifications or by the client. For FDEM the classification specifications are ground, default, noise, water and overlap (Classes: 1, 2, 7, 9 and 12). Once the data is classified, the entire data set is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract guidelines, whichever apply. Table 8 indicates the required product specifications.

The coordinate and datum transformations are then applied to the data set to reflect the required deliverable projection, coordinate and datum systems as provided in the contract.

The client required deliverables are then generated. At this time, a final QC process is undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn’s Quality control/ quality assurance department reviews the data and then releases it for delivery.

Table 8: Processing Accuracies and Requirements

Accuracy of LiDAR Data (H)	50 cm RMSE
Accuracy of LiDAR data in bare areas	9.25 cm RMSE
Accuracy of LiDAR data in vegetated areas	18.5 cm RMSE
Percent of artifacts removed (terrain and vegetation dependent)	95%
Percent of all outliers removed	95%
Percent of all vegetation removed	95%
Percent of all buildings removed	98%

5 GEODETIC BASE NETWORK

5.1 Network Scope

During the LiDAR campaign, the geodetic control survey and final coordinates were provided to Sanborn by the PDS team. For Okaloosa County the Sanborn crew set up on NGS points BG2048, BG4869, and BG5100 which was set at the airport. These three points were tied into the fully constrained network that was provided.

5.2 Final LiDAR Verification

Figure 6 shows a diagram of the collected checkpoints for Okaloosa County. For the Okaloosa County checkpoint control report the standard deviation is 0.217 feet and the root mean squared is 0.268 feet. The LiDAR data was compared to each of these classes yielding much better result than was required for the project. Points indicating removed are points outside the statistical variance in the data. Table 9 indicates the results for Okaloosa County and each point including the overall results as it compares to the LiDAR data set.

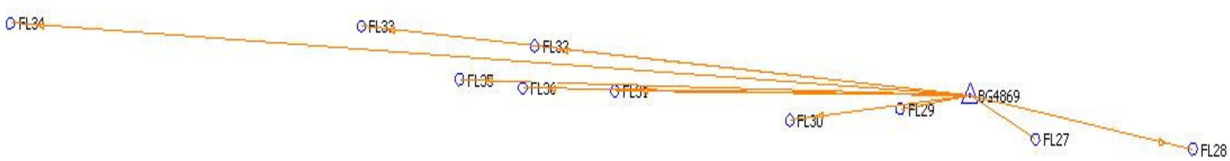

Figure 6: FDEM Survey Checkpoint Diagram for Okaloosa County

Table 9: FDEM Okaloosa County Checkpoint Results (US Survey Feet)

Number	Easting	Northing	Known Z	Laser Z	Dz
58	1348052.686	512832.893	17.582	17.830	+0.248
60	1370170.444	508448.356	18.002	17.980	-0.022
62	1330096.404	511420.106	4.465	4.410	-0.055
3	1297313.220	515084.599	5.512	5.440	-0.072
59	1354506.580	509513.565	12.211	12.120	-0.091
61	1341096.642	512014.327	24.449	24.290	-0.159
1	1287615.772	519161.215	22.021	21.690	-0.331
4	1303586.387	514334.312	6.020	5.630	-0.390
63	1312745.269	513928.007	5.928	5.510	-0.418
2	1252723.412	520136.980	10.761	10.340	-0.421

Average dz -0.171
Minimum dz -0.421
Maximum dz +0.248
Average magnitude 0.221
Root mean square 0.268
Std deviation 0.217

6 GROUND CONTROL REPORT

6.1 Introduction

This section addresses Ground Control reporting in the Ellipsoid model used as part of the collection and the Geoid model used to compute orthometric heights.

6.2 Horizontal Datum

The horizontal datum associated with the LiDAR data is NAD83 (1993)/HARN, as realized by the physical NGS control monuments used to constrain the survey control network.

6.3 Vertical Datum

The vertical datum associated with the LiDAR data is the NAVD88, as realized by the physical NGS benchmarks used to constrain the survey control network.

Appendix E: QA/QC Checkpoints and Accuracy Spreadsheets

Point Number		Land Cover Class	SPCS NAD83/99 North Zone		NAVD88	LIDAR-Z	ΔZ
			Easting-X (Ft)	Northing-Y (Ft)	Survey-Z (Ft)		
OK001M3	1	BE & Low Grass	1248958.17	522222.44	28.40	28.49	0.09
OK002M10	1	BE & Low Grass	1263500.52	520329.22	15.93	16.20	0.27
OK003M7	1	BE & Low Grass	1280444.55	519437.90	6.08	6.31	0.23
OK004M11	1	BE & Low Grass	1304197.81	523783.64	7.58	7.19	-0.39
OK005M7	1	BE & Low Grass	1300274.26	539114.74	54.71	54.62	-0.09
OK006M3	1	BE & Low Grass	1320712.53	551235.32	84.22	83.89	-0.33
OK007M7	1	BE & Low Grass	1344191.15	518973.52	15.57	15.62	0.05
OK008M4	1	BE & Low Grass	1357807.66	562883.96	76.18	75.89	-0.29
OK009M4	1	BE & Low Grass	1373714.40	537428.92	16.61	16.68	0.07
OK010M1	1	BE & Low Grass	1372842.44	508826.87	12.12	12.50	0.38
OK002M4	2	Brush & Low Trees	1263346.32	520489.98	17.76	18.58	0.82
OK003M8	2	Brush & Low Trees	1280516.82	519376.22	7.39	7.42	0.03
OK004M5	2	Brush & Low Trees	1304349.03	523788.47	3.96	3.87	-0.09
OK005M2	2	Brush & Low Trees	1300168.88	539050.09	54.84	54.84	0.00
OK006M7	2	Brush & Low Trees	1320772.85	550956.28	83.01	82.95	-0.06
OK007M1	2	Brush & Low Trees	1344240.32	518997.56	14.81	14.78	-0.03
OK008M9	2	Brush & Low Trees	1357827.25	562913.93	79.32	79.20	-0.12
OK009M9	2	Brush & Low Trees	1373843.63	537397.32	16.04	16.28	0.24
OK010M6	2	Brush & Low Trees	1372515.71	508830.48	14.74	15.12	0.38
OK001M5	2	Brush & Low Trees	1248866.64	522238.23	28.67	27.95	-0.72
OK001M11	3	Forested	1248821.91	522384.34	29.30	28.54	-0.76
* OK002M12	3	Forested	1263355.90	520297.12	13.07	13.83	0.76
* OK003M11	3	Forested	1280677.08	519296.18	8.60	9.49	0.89
* OK004M2	3	Forested	1304338.06	523715.56	2.59	4.57	1.98
OK005M4	3	Forested	1300147.81	539013.03	54.36	55.00	0.64
OK006M8	3	Forested	1320802.39	551030.98	83.27	83.94	0.67
OK007M2	3	Forested	1344293.95	518992.40	14.32	13.76	-0.56
OK008M7	3	Forested	1357851.77	563011.62	81.56	81.46	-0.10
OK009M2	3	Forested	1373747.90	537476.19	15.95	16.16	0.21
* OK010M3	3	Forested	1372694.86	508862.17	13.09	14.11	1.02
OK001M9	4	Urban	1248935.53	522108.76	29.21	29.40	0.19
OK002M9	4	Urban	1263462.27	520322.57	16.23	16.09	-0.14
OK003M4	4	Urban	1280730.83	519472.90	11.43	11.20	-0.23
OK004M7	4	Urban	1304344.77	523747.84	6.85	5.96	-0.89
OK005M11	4	Urban	1300201.22	538883.20	53.25	53.06	-0.19
OK006M6	4	Urban	1320753.98	551097.95	87.05	86.68	-0.37
OK007M8	4	Urban	1344216.25	518976.34	15.43	14.96	-0.47
OK008M1	4	Urban	1357752.57	563005.66	77.55	77.18	-0.37
OK009M7	4	Urban	1373680.29	537183.10	17.80	17.64	-0.16
OK010M7	4	Urban	1372551.38	508740.24	15.92	16.10	0.18

* OK002M12 was located in a low confidence area and was not used in the vertical accuracy assessment

* OK003M11 was located in a low confidence area and was not used in the vertical accuracy assessment

* OK004M2 was located in a low confidence area and was not used in the vertical accuracy assessment

* OK010M3 was located in a low confidence area and was not used in the vertical accuracy assessment

Okaloosa County - Vertical Accuracy Assessment for All Categories Combined						
PID	Land Cover Cat.	LiDAR TIN Z	Survey Height	DELTA Z	DZ *2	ABS DZ
OK001M3	1	28.49	28.40	0.09	0.01	0.09
OK002M10	1	16.20	15.93	0.27	0.07	0.27
OK003M7	1	6.31	6.08	0.23	0.05	0.23
OK004M11	1	7.19	7.58	-0.39	0.15	0.39
OK005M7	1	54.62	54.71	-0.09	0.01	0.09
OK006M3	1	83.89	84.22	-0.33	0.11	0.33
OK007M7	1	15.62	15.57	0.05	0.00	0.05
OK008M4	1	75.89	76.18	-0.29	0.08	0.29
OK009M4	1	16.68	16.61	0.07	0.01	0.07
OK010M1	1	12.50	12.12	0.38	0.14	0.38
OK002M4	2	18.58	17.76	0.82	0.67	0.82
OK003M8	2	7.42	7.39	0.03	0.00	0.03
OK004M5	2	3.87	3.96	-0.09	0.01	0.09
OK005M2	2	54.84	54.84	0.00	0.00	0.00
OK006M7	2	82.95	83.01	-0.06	0.00	0.06
OK007M1	2	14.78	14.81	-0.03	0.00	0.03
OK008M9	2	79.20	79.32	-0.12	0.01	0.12
OK009M9	2	16.28	16.04	0.24	0.06	0.24
OK010M6	2	15.12	14.74	0.38	0.15	0.38
OK001M5	2	27.95	28.67	-0.72	0.51	0.72
OK001M11	3	28.54	29.30	-0.76	0.58	0.76
OK005M4	3	55.00	54.36	0.64	0.41	0.64
OK006M8	3	83.94	83.27	0.67	0.45	0.67
OK007M2	3	13.76	14.32	-0.56	0.32	0.56
OK008M7	3	81.46	81.56	-0.10	0.01	0.10
OK009M2	3	16.16	15.95	0.21	0.04	0.21
OK001M9	4	29.40	29.21	0.19	0.04	0.19
OK002M9	4	16.09	16.23	-0.14	0.02	0.14
OK003M4	4	11.20	11.43	-0.23	0.05	0.23
OK004M7	4	5.96	6.85	-0.89	0.80	0.89
OK005M11	4	53.06	53.25	-0.19	0.04	0.19
OK006M6	4	86.68	87.05	-0.37	0.14	0.37
OK007M8	4	14.96	15.43	-0.47	0.22	0.47
OK008M1	4	77.18	77.55	-0.37	0.14	0.37
OK009M7	4	17.64	17.80	-0.16	0.03	0.16
OK010M7	4	16.10	15.92	0.18	0.03	0.18
	Geo-Referencing			sum of dz²	5.36	
	Horiz	NAD83(1992) NZ		count	36.00	
	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.15	
	Units	US Survey Feet		RMSE	0.39	
				1.96 * RMSE	0.76	
	RMSE Calculation			mean	-0.05	

	Square Root of $\sum(Zn-Z'n)^2/N$			median	-0.07	
	Zn = LiDAR Dem Heights			skew	0.04	
	Z'n = Checkpoint Heights			std dev	0.39	
	N = The number of check points			**95th percentile**	**0.78**	

Ground Cover CAT	CAT Description	Survey CAT	Surv. CAT Ground Cover Equivalent	DZ MIN	DZ MAX
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass	-0.89	0.82
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees		
CAT 3	Forested	GND 3	GND 3 = Ground - Forested		
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road		
			PVM = Pavement (Asphalt/Concrete)		
			MGF= Well Maintained Ground Feature		

Land Cover Categories and Accuracy Criteria			Computed Accuracies		
Ground Cover CAT	RMSEz (Ft) ≤	ACCURACYz (Ft) ≤	RMSEz	95% Acc Z	95th Percentile
CAT 1	0.30	0.60	0.25	0.49	0.38
CAT 2	0.61	1.19	0.38	0.74	0.77
CAT 3	0.61	1.19	0.55	1.08	0.74
CAT 4	0.61	1.19	0.39	0.76	0.70
COMBINED	0.61	1.19	0.39	0.76	0.78

Calculation of Estimated and Actual Number of Check Points and Clusters for This County Area

Total Number of Tiles This County Area	Square Miles Per 5K Tile	Total Square Miles This County Area	Number of Check Points per Sq. Mi.	Estimated Number of Check Points	Estimated Number of Point Clusters	Actual No. of Points / Clusters
178	0.897	160	4.17	38	10	38 /10

The following CAT 3 check points were located in or near low confidence areas and were not used in the vertical accuracy assessment

Point No	Land Cover Class	LiDAR TIN Z	Survey - Z	ΔZ	ΔZ*2	ABS ΔZ
OK004M2	3	4.31	2.59	1.72	2.94	1.72
OK010M3	3	14.11	13.09	1.02	1.03	1.02
OK002M12	3	13.83	13.07	0.76	0.58	0.76
OK003M11	3	9.49	8.60	0.89	0.79	0.89

100 % of Totals	# of Points	RMSE (ft) Spec = 0.61 (BE = 0.30)	Mean (ft)	Median (ft)	Min (ft)	Max (ft)
Consolidated	36	0.39	-0.05	-0.07	-0.89	0.82
BE & Low Grass	10	0.25	-0.00	-0.06	-0.39	0.38
Brush & Low Trees	10	0.38	0.05	0.01	-0.72	0.82
Forested	6	0.55	0.02	0.06	-0.76	0.67
Urban	10	0.39	-0.25	-0.21	-0.89	0.19

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Consolidated	36		0.78	
BE & Low Grass	10	0.49		0.38
Brush & Low Trees	10			0.77
Forested	6			0.74
Urban	10			0.70

Appendix F: LiDAR Vertical Accuracy Report

Vertical Accuracy Assessment Report
2007 LiDAR Bare-Earth Dataset for
Okaloosa County, Florida

Date: May 5, 2008

References: A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a
B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003
D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Background
<u>FDEM Guidance</u>: Reference A tasked PDS to validate the bare-earth LiDAR dataset of Okaloosa County, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the vertical accuracy assessment only, for which FDEM's major specifications are summarized as follows:

- Vertical accuracy: $\leq$ 0.30 feet $RMSE_z$ = $\leq$ 0.60 feet vertical accuracy at 95% confidence level, tested in flat, non-vegetated terrain only, employing NSSDA procedures in Reference B.
- Validation that the data also satisfies FEMA requirements in Reference C.
- Vertical units (orthometric heights) are in US Survey Feet, NAVD88.

<u>NSSDA Guidance</u>: Section 3.2.2 of Reference B specifies: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

<u>FEMA Guidance</u>: Section A.8.6 of Reference C specifies the following LiDAR testing requirement for data to be used by the National Flood Insurance Program (NFIP): "For the NFIP, TINs (and DEMs derived there from) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied … The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following: [followed by explanations of seven potential categories]… Ground cover Categories 1 through 5 are fairly common everywhere … The assigned Mapping Partner shall select a minimum of 20 test points for <u>each</u> major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on."

Note: for this project PDS followed the FDEM guidelines in Reference A, which stipulates that the vertical accuracy report will be based on a minimum of 30 ground measurements for each of four land cover categories, totaling 120 test points for each 500 square mile area of new topographic data collection. Note Okaloosa County contained a relatively small number of tiles and there were only 10 checkpoints established in each land cover category. The land cover measurements distributed through each project area will be collected for each of the following land cover categories:

1. Bare-earth and low grass
2. Brush Lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

NDEP and ASPRS Guidance: NDEP guidelines (Reference D) and ASPRS guidelines (Reference E) also recommend a minimum of 60 checkpoints, with up to 100 points preferred. (These guidelines are referenced because FEMA's next update to Appendix A will include these newer NDEP and ASPRS guidelines, now recognizing that vertical errors for LiDAR bare-earth datasets in vegetated terrain do not necessarily follow a normal error distribution as assumed by the NSSDA.)

Vertical Accuracy Test Procedures

Ground Truth Surveys: The PDS team established a primary geodetic network covering approximately 6,000 square miles along the panhandle area of Northwest Florida to provide accurate and consistent control throughout the project area, which includes Okaloosa County. The Primary Network was used to establish base stations to support airborne GPS data acquisition. Two Secondary control networks were established to support the measurement of checkpoints used in the accuracy validation process for newly generated LiDAR and Orthophotography.

Assessment Procedures and Results: The LiDAR accuracy assessment for Okaloosa County was performed in accordance with References D and E which assume that LiDAR errors in some land cover categories may not follow a normal error distribution. This assessment was also performed in accordance with References B and C which assume that LiDAR bare-earth datasets errors do follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in Okaloosa County's four major land cover categories: (1) bare-earth and low grass, (2) brush lands and low trees, (3) forested areas fully covered by trees, (4) urban areas. When a LiDAR bare-earth dataset passes testing by both methods, compared with criteria specified in Reference A, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for FDEM and FEMA requirements.

The relevant testing criteria, as stipulated in Reference A are summarized in Table 1.

Table 1 — DTM Acceptance Criteria for Okaloosa County

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	0.60 ft (0.30 ft $RMSE_z$ x 1.96000) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	1.19 ft (based on 95th percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References D and E specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). FVA determines how well the LiDAR sensor performed in category (1), open terrain, where errors are random and normally distributed; whereas SVA determines how well the vegetation classification algorithms worked in land cover categories (2) and (3) where LiDAR elevations are often higher than surveyed elevations and category (4) where LiDAR elevations are often lower.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600, as specified in Reference B. For Okaloosa County, for which floodplains are essentially flat, FDEM required the FVA to be 0.60 ft (18.29 cm) at the 95% confidence level (based on an $RMSE_z$ of 0.30 ft (9.14 cm), equivalent to 1 ft contours).

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all land cover categories combined. FDEM's CVA standard is 1.19 ft at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, brush lands and low trees, forested areas, and urban areas, in order to facilitate the analysis of the data based on each of these land cover categories that exist within Okaloosa County. The SVA criteria in Table 1 (1.19 ft at the 95% confidence level for each category) are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy FEMA's mandatory CVA criterion.

<u>QA/QC Steps</u>: The primary QA/QC steps used by PDS were as follows:

1. PDS surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of "cluster areas" where PDS attempted to survey a minimum of 10 QA/QC checkpoints in each of the four land cover categories. Some cluster areas may not include all land cover categories. The final totals were 10 checkpoints in bare-earth and low grass; 10 checkpoints in brush and low trees; 6 checkpoints in forested areas; and 10 checkpoints in urban areas, for a total of 36 checkpoints.
2. Next, PDS interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 36 checkpoints.
3. PDS then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values using procedures in References D and E.

4. The data were analyzed by PDS to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by FDEM guidelines. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

Figure 1 shows the location of the QA/QC checkpoint clusters within Okaloosa County. Each point represents a checkpoint cluster. There are nominally four checkpoints in each cluster, one per land cover category.

Figure 1 — Location of QA/QC Checkpoint Clusters for Okaloosa County

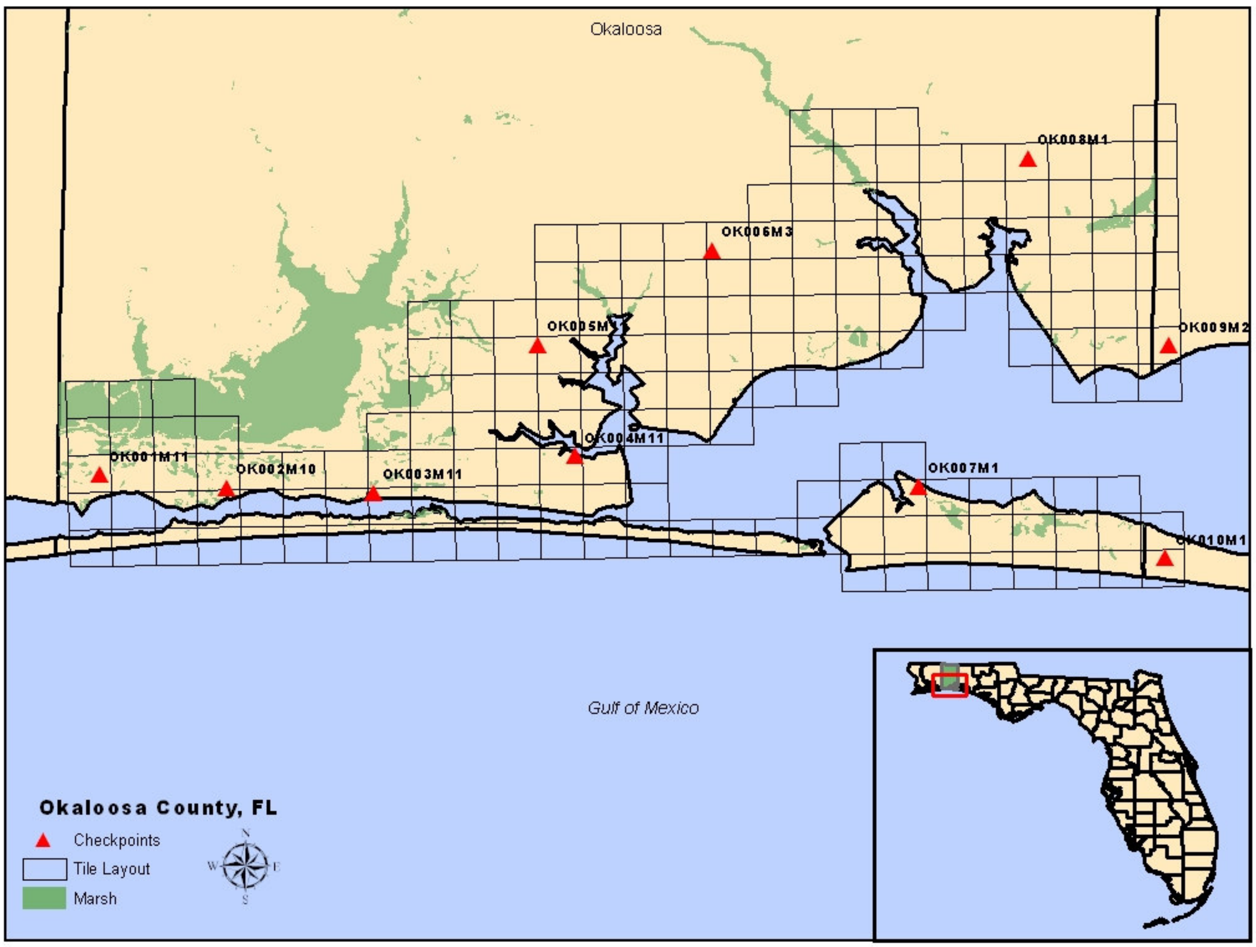

Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Total Combined	36		0.78	
BE & Low Grass	10	0.49		0.38
Brush & Low Trees	10			0.77
Forested	6			0.74
Urban	10			0.70

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NDEP/ASPRS methodology:

The $RMSE_z$ in bare-earth and low grass was within the target criteria of 0.30 ft, and the FVA tested 0.49 ft at the 95% confidence level in open terrain, based on $RMSE_z$ x 1.9600.

Compared with the 1.19 ft specification, CVA tested 0.78 ft at the 95% confidence level in bare-earth and low grass, brush and low trees, forested, and urban areas combined, based on the 95th Percentile. Table 3 lists the 5% outliers larger than the 95th percentile error; whereas 5% of the points could have exceeded the 1.19 ft criterion, no points actually exceeded this criterion.

Table 3 — 5% Outliers Larger than 95th Percentile

<table>
<tr><th>Land Cover Category</th><th>Elevation Diff. (ft)</th><td rowspan="8">No points exceeded the 1.19 ft 95th percentile criteria</td></tr>
<tr><td></td><td></td></tr>
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</table>

Compared with the 1.19 ft SVA target values, SVA tested 0.38 ft at the 95% confidence level in bare-earth and low grass; 0.77 ft in brush and low trees; 0.74 ft in forested areas; and 0.70 ft in urban areas, based on the 95th Percentile. Each of the four land cover categories were well within the target value of 1.19 ft.

Figure 2 illustrates the SVA by specific land cover category.

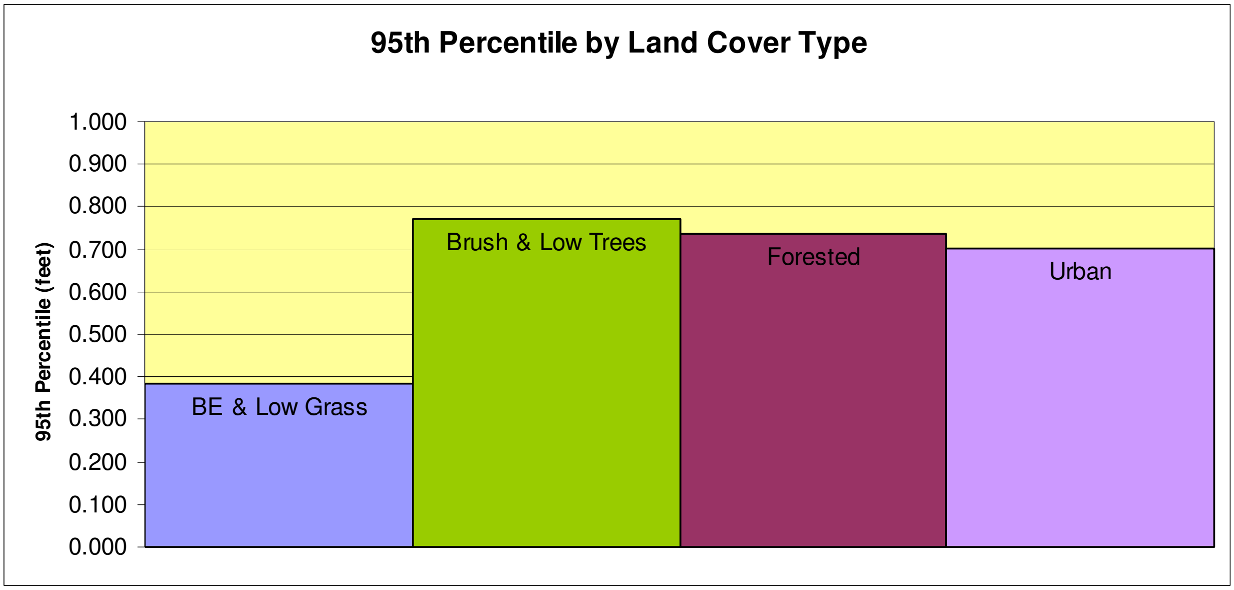

Figure 2 — Graph of SVA Values by Land Cover

Figure 3 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest. This shows a normal distribution of points in all categories except Urban, which has a negative skew. Also, of significant note is the fact that there were no checkpoints in any of the four land cover classifications that exceed the 1.19 ft SVA accuracy criteria.

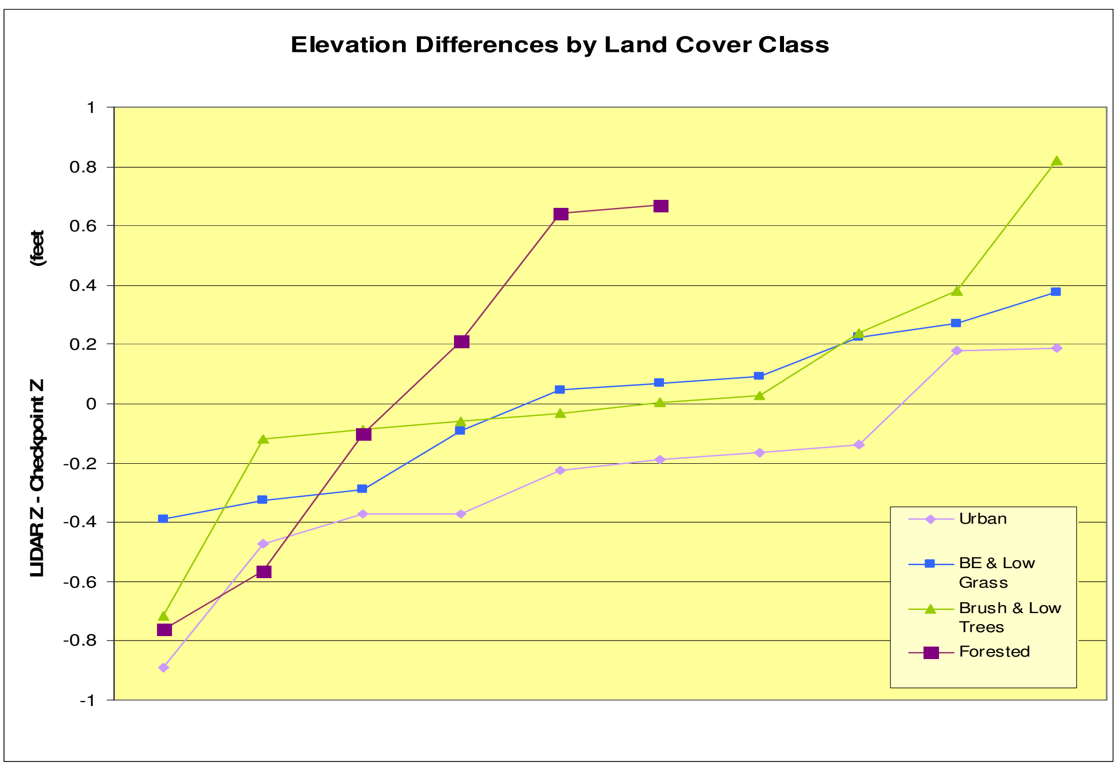

Figure 3 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

The NSSDA and FEMA guidelines were both published before it was recognized that LiDAR errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, $RMSE_z$ statistics were computed in all four land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the LiDAR data. These statistics are summarized in Figures 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference C.

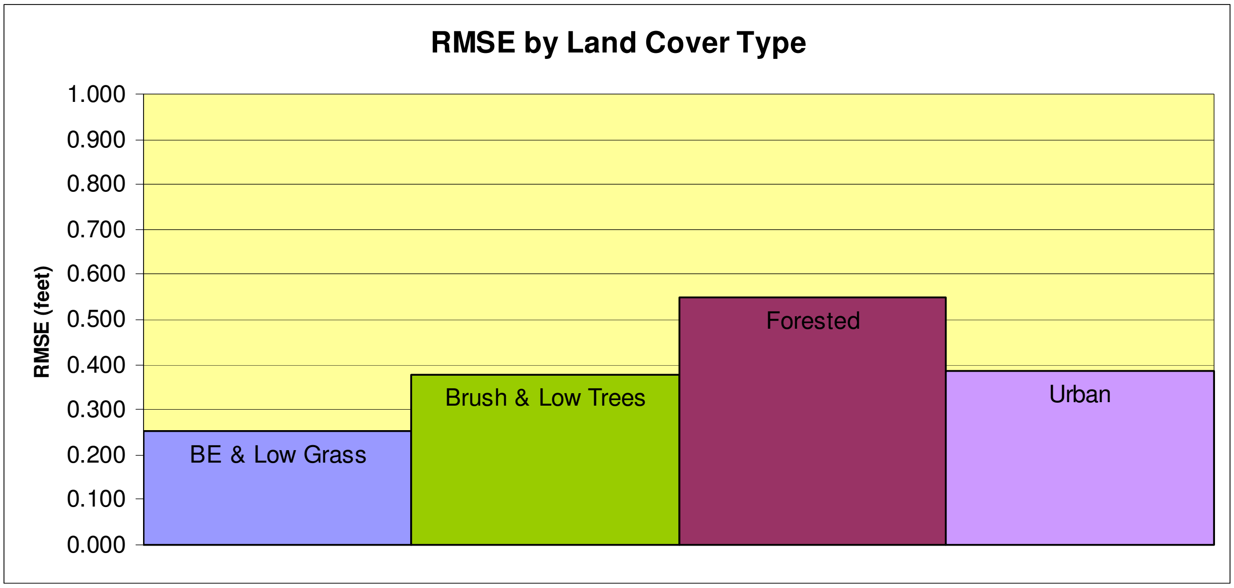

Figure 4 — $RMSE_z$ statistics by Land Cover Category

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

Descriptive Statistics							
Land Cover Category	**Points**	**RMSE (feet)**	**Mean Error (feet)**	**Median Error (feet)**	**SKEW**	**STDEV (feet)**	**95th Percentile (feet)**
Consolidated	36	0.39	-0.05	-0.07	0.04	0.39	0.78
BE & Low Grass	10	0.25	0.00	0.06	-0.22	0.27	0.38
Brush & Low Trees	10	0.38	0.05	-0.01	0.13	0.39	0.77
Forested	6	0.55	0.02	0.06	-0.19	0.60	0.74
Urban	10	0.39	-0.25	-0.21	-0.56	0.31	0.70

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NSSDA/FEMA methodology:

Although the NSSDA and FEMA guidelines predated FVA and CVA terminology, vertical accuracy at the 95% confidence level (called $Accuracy_z$) is computed by the formula $RMSE_z$ x 1.9600. $Accuracy_z$ in open terrain = 0.25 ft x 1.9600 = 0.49 ft, satisfying the 0.60 ft FVA standard. $Accuracy_z$ in consolidated categories = 0.39 ft x 1.9600 = 0.78 ft, satisfying the 1.19 ft CVA standard.

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. The discrepancies vary between a low of -0.89 ft and a high of +0.82 ft and approximate a “bell curve” with mean of zero.

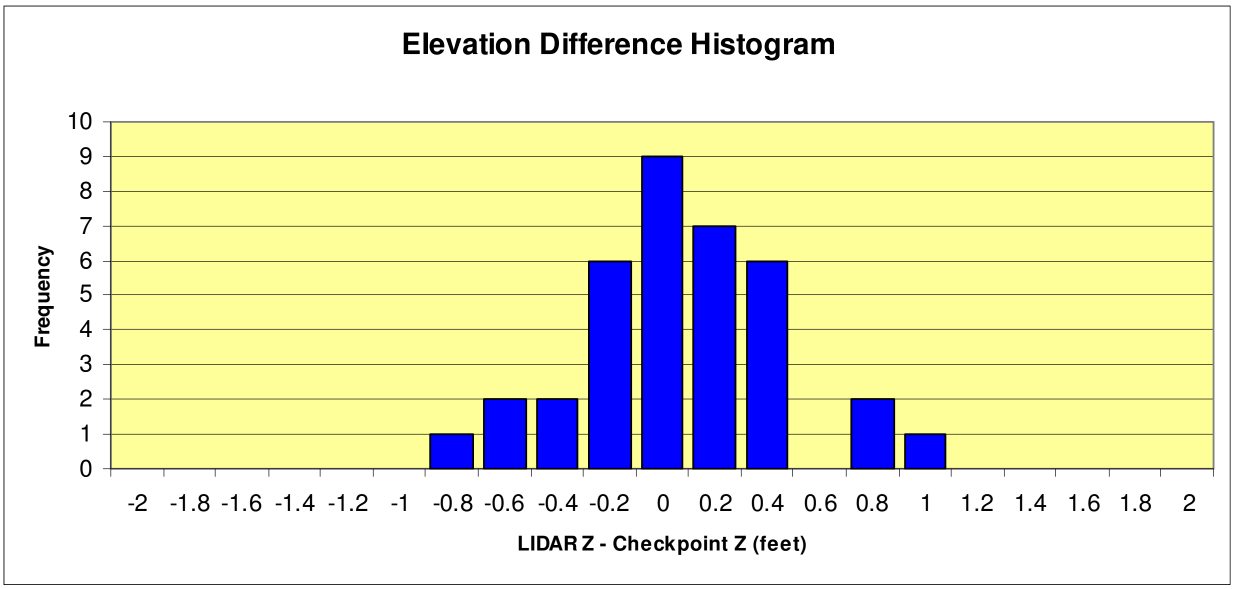

Figure 5 — Histogram of Elevation Discrepancies within 0.20 ft Bands

Checkpoints That Were Not Used

The following Category 3 (forested area) checkpoints were located in the low confidence areas exhibiting limited point density: OK004M2, OK010M3, OK002M12 and OK003M11. These checkpoints were not used in the vertical accuracy assessment.

Figure 6 and 7 shows the digital pictures captured in the field and the corresponding point density grids for Category 3 checkpoints OK004M2, OK010M3, OK002M12 and OK003M11. The density grids were generated at a default cell size of 4 ft. “Dense” data is color green; dense is defined as a data point with an adjacent point equal to or less than the selected grid spacing of 4 ft. Sparse data is colored red; dense data is defined a point with the closest adjacent point greater than four times the selected grid spacing of 4 ft.

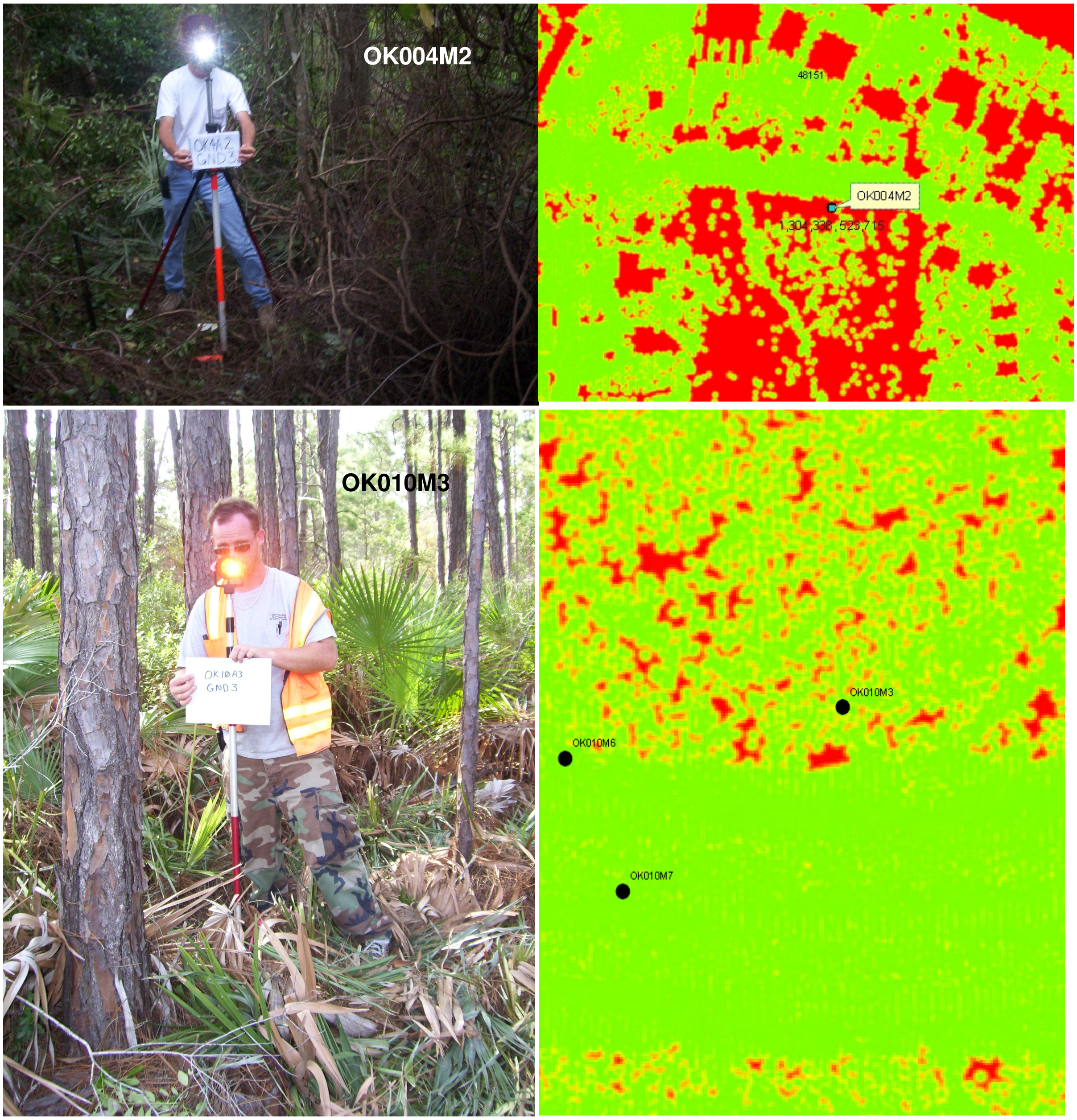

Figure 6 — Pictures showing locations density grids for checkpoints OK004M2 and OK010M3

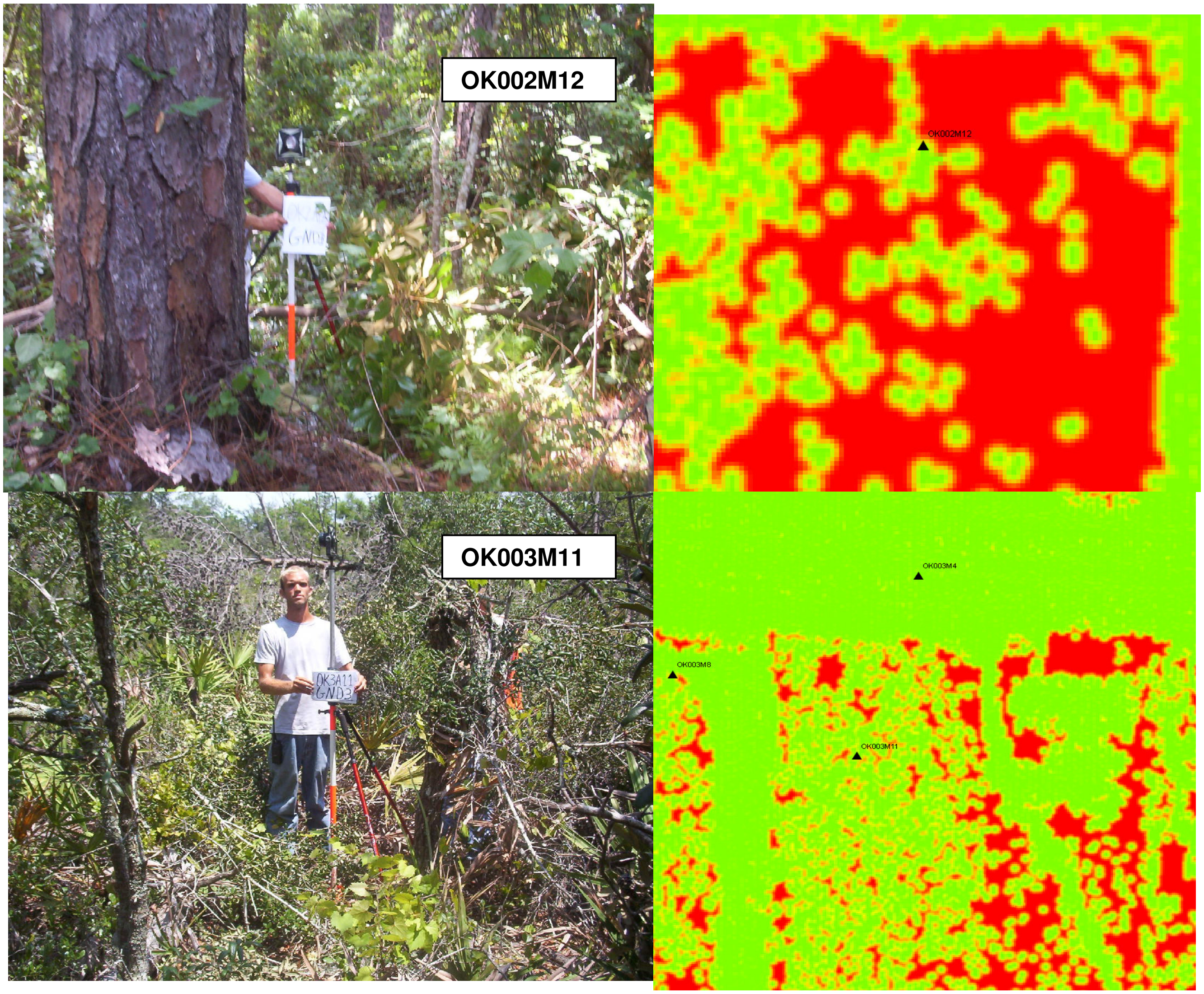

Figure 6 — Pictures showing locations density grids for checkpoints OK002M12 and OK003M11

Conclusions

Based on the vertical accuracy testing conducted by PDS, the undersigned certifies that the LiDAR dataset for Okaloosa County, Florida satisfies the criteria established by Reference A:

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.49' vertical accuracy at 95% confidence level in open terrain.**

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.78' vertical accuracy at 95% confidence level in all land cover categories combined.**

David F. Maune, Ph.D., PSM, PS, GS, CP
QA/QC Manager

Appendix G: LiDAR Qualitative Assessment Report

References:

A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a

B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998

C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003

D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004

E — *ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Qualitative Assessment

The PDS qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model. Overall the data are of good quality and should satisfy most users for an accurate bare-earth elevation data product.

Overview

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR point spacing for this project is two meters or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional, elevation mapping technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, PDS employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but the PDS team can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

Analysis

Process

PDS utilizes GeoCue software products as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. PDS uses Microsoft SQL Server as the database of choice.

The PDS qualitative assessment process flow for Okaloosa County, FL incorporated the following reviews:

1. *Statistical Analysis*- A statistical analysis routine was run on the .LAS files upon receipt to verify that the .LAS files met project specifications. This routine checked for the presence of Variable Length Records, verified .LAS classifications, verified header records for min/max x,y,z, and parsed the .LAS point file to confirm that the min/max x,y,z matched the header records. These statistics were run on the all-return point data set as well as the bare-earth point data set for every deliverable tile.
    a. All LAS files contained Variable Length Records with georeferencing information.
    b. All LiDAR points in the LAS files were classified in accordance with project specifications: Class 1 - Unclassified, Class 2 - Ground, Class 7 - Noise, and Class 9 – Water, Class 12-Overlap.
    c. Min/max x,y,z values matched the header files.

2. *Spatial Reference Checks*- The .LAS files were imported into the GeoCue processing environment. As part of the URS process workflow the GeoCue import produced a minimum bounding polygon for each data file. This minimum bounding polygon was one of the tools used in conjunction with the statistical analysis to verify spatial reference integrity. No issues were identified with the spatial referencing of this dataset.

3. *Data Void/ Gap Checks*-The imported .LAS files were used to create LiDAR “orthos” (Figure 1). The LiDAR orthos were one of the tools used to verify data coverage and point density, to check for data voids or gaps, and to use as reference data during checks for data anomalies and artifacts. This product is not intended to be a project deliverable. The orthos were derived from the Full Point Cloud elevations and LiDAR pulse return intensity values. The intensity values were used as delivered with no normalization applied.

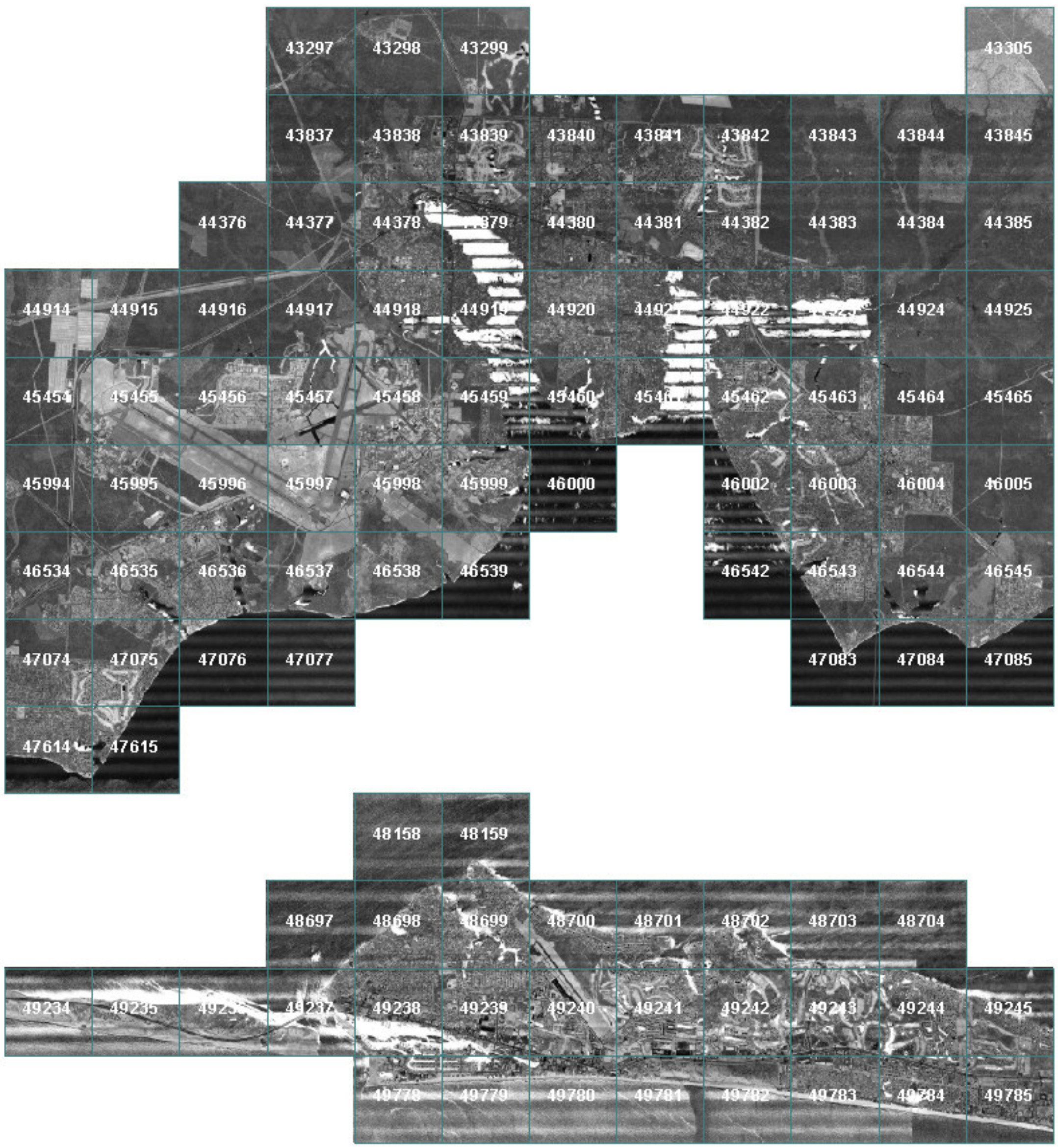

Figure 9 Okaloosa County LiDAR Orthos produced from Intensity Returns

Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids (Figure 2).

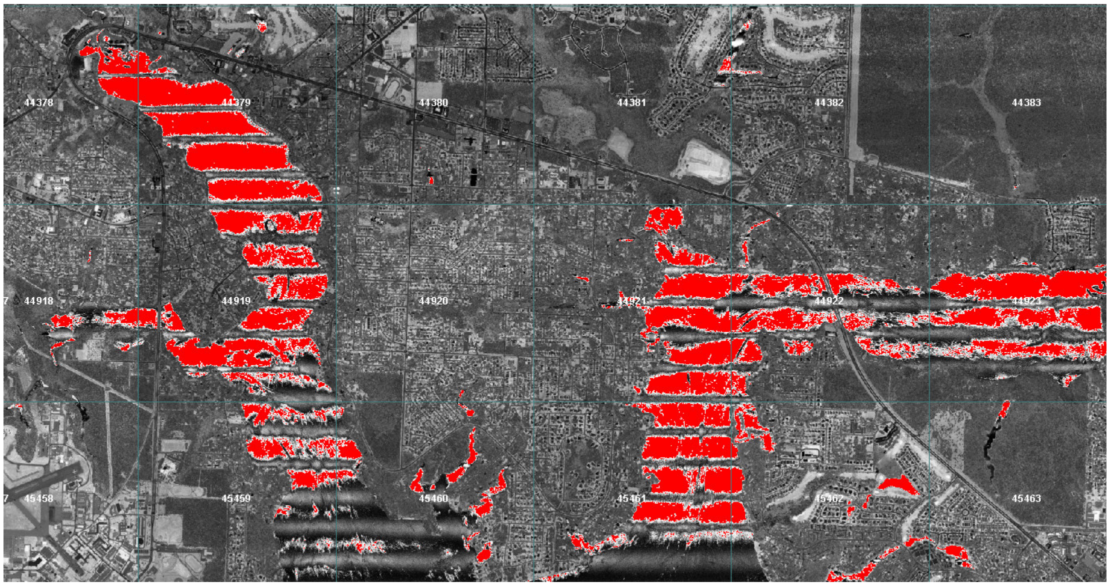

Figure 10 Acceptable voids in data due to water bodies

For Okaloosa County, additional voids were found on features such as residential and commercial rooftops and paved surfaces in parking lots and on roads. Instances of these voids occur randomly throughout the dataset (Figures 3 & 4). All voids found were reviewed and determined to be within acceptable ranges.

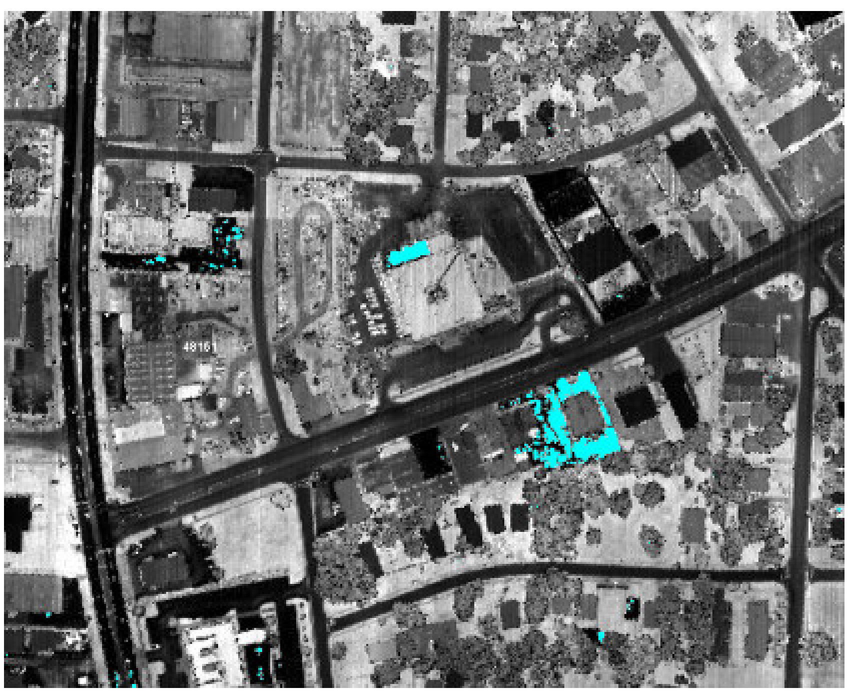

Figure 11: Overview showing areas of data voids in parking lots and buildings

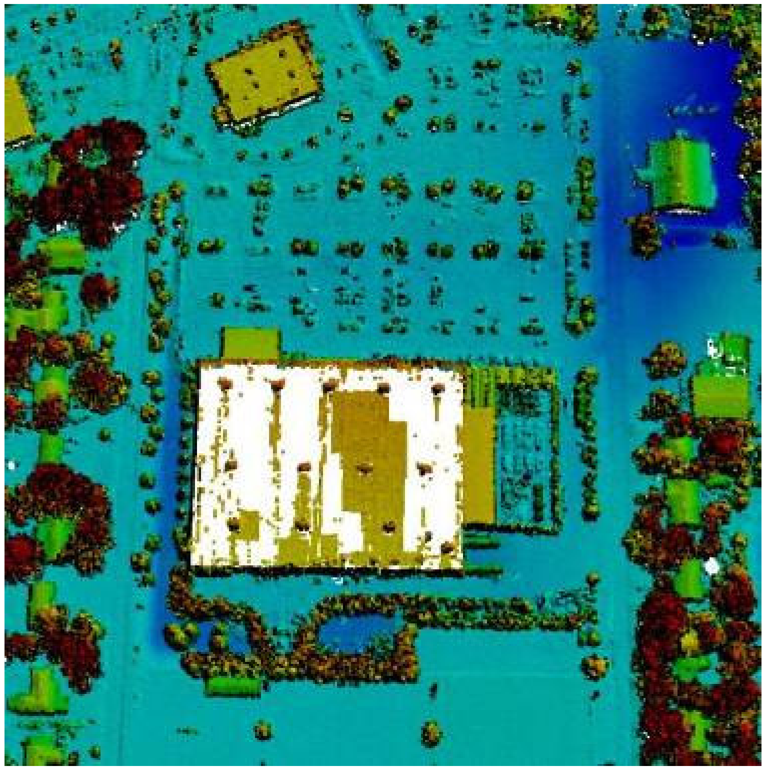

Figure 12 Colorized point cloud showing lack of data on commercial rooftop

4. *Initial Data Verification:* PDS performs an initial 10% random check of the data delivery by looking at each tile individually in great detail utilizing TIN surfaces and profiles. If the data set passes the 10 % check, the tiles continue through the remaining QC work flow where every tile is reviewed. If the data set fails the 10% check it is normally due to a systematic process error and the data set is sent back to the vendor for correction. Upon receipt of the corrected tile/s the check is performed again to ensure that any flagged errors were corrected and additional issues were not inadvertently introduced during the corrective action.

5. *Data Density/Elevation checks:* The .LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2(ground points) in the .LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the FDEM project it is stipulated that the maximum post spacing in un-obscured areas should not exceed 1.2m.

   Model statistics were produced and characterized by density, scale, intensity, and elevation. (Figure 5) The low confidence area polygons were overlaid onto the density grids to ensure that all low confidence areas were properly identified with a polygon. As with the LiDAR orthos, this product was produced for Quality Assessment purposes only.

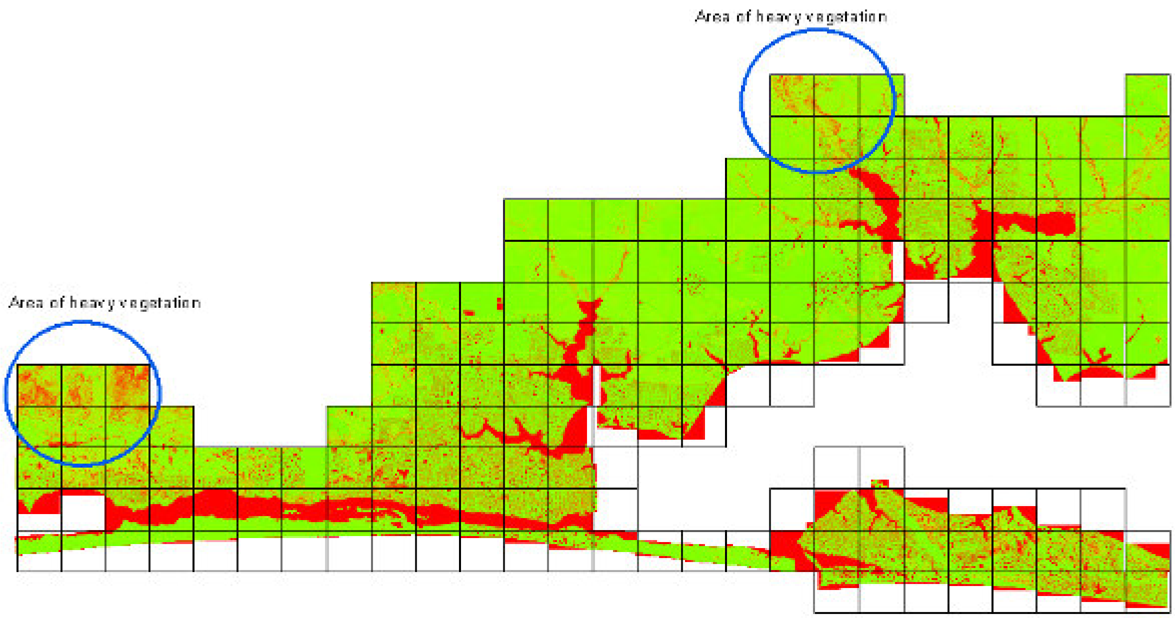

Figure 13 Density grid of Okaloosa County, created using a green to red color ramp. Green areas meet project specifications; red delineates areas not meeting minimum density requirements (primarily water and low-confidence areas)

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6. *Artifact Anomaly Checks.* The final step in the analysis was to review every tile for anomalies that may exist in the bare-earth terrain surface. Items that were checked include, but are not limited to: buildings, bridges, vegetation and water points classified as Class 2 points and elevation "steps" that may occur in the overlap between adjacent flight lines. Any issues found are addressed in the below "General comments and issues".

General comments and issues

The project area in Okaloosa County, Florida is predominantly an urban area. There are no national or state forests and there are two small state parks. A portion of the Eglin Air Force Base proper was included in the project area (Figure 6).

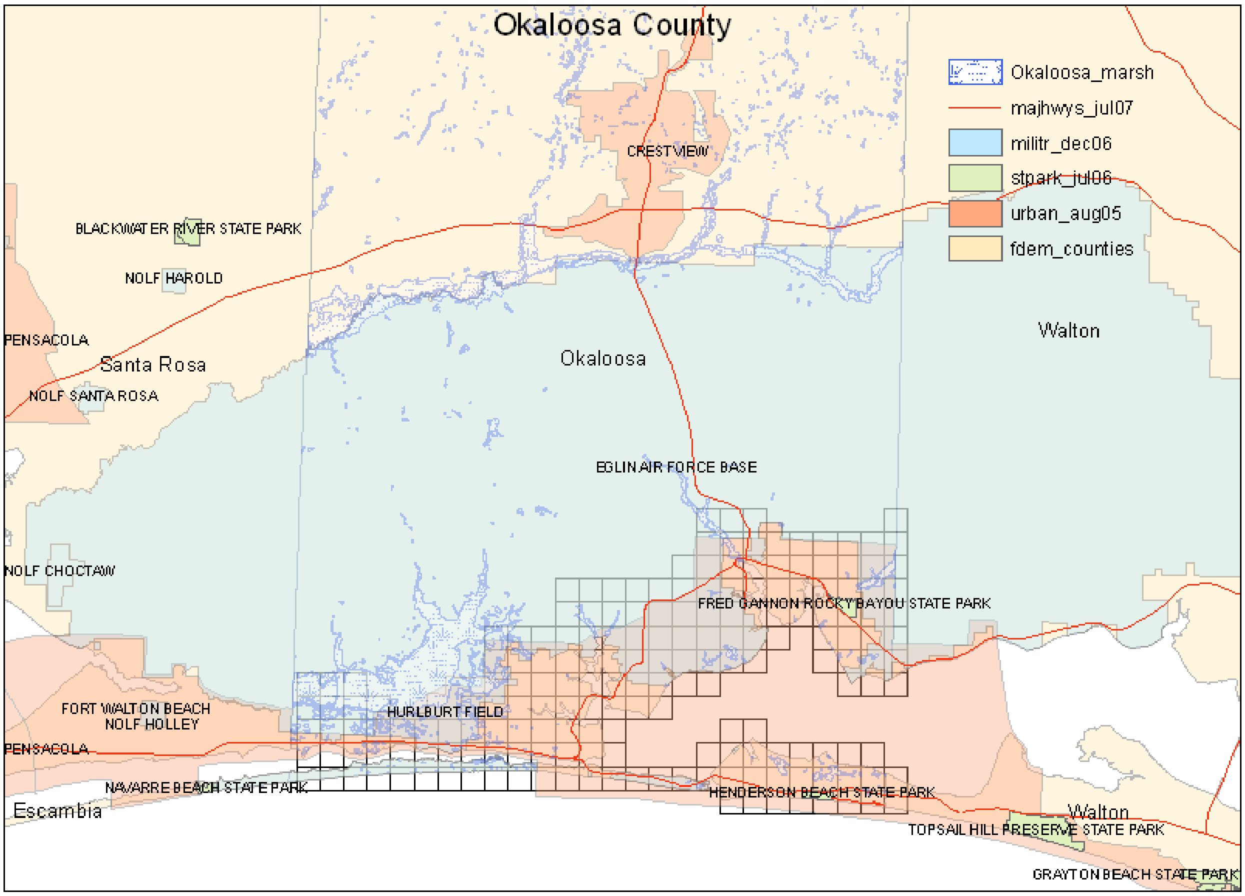

Figure 14 Map of Okaloosa County Florida with marsh areas from Florida Geographic Data Library (FGDL)

The initial data acquisition was very dense. Overall the acquired point density was around 0.45m. In general, the bare earth ground surface was clear of artifacts and very clean. The algorithms used to classify the above-ground ground points were very stringent; given the overall physical characteristics of the county this does not seem inappropriate. There is a fine line in the decision-making process of which points to classify as ground. By removing points from the ground classification due to heavy vegetation there is risk of over-smoothing or "flattening" the ground surface which can have a greater impact than leaving points to maintain the ground surface model. In addition, due to the lack of significant elevation changes in the physical terrain there are places where there is no visible break in the terrain between the ground surface and what in traditional mapping would be considered a hard breakline feature, for example roads.

Because the project includes the collection of breaklines, this will be compensated for in the hard breakline collection. The LiDAR data contained sporadic issues such as artifacts or small anomalies which is typical of any LiDAR dataset. Due to the presence of dense vegetation throughout the county, the low confidence area polygons and breaklines are important deliverables for this particular county.

The bare earth terrain model was checked for consistency in bare earth processing, tile edge-match with neighboring tiles, flight line edge match, correct water classification and bridge, building and vegetation removal. There were some issues noted in the qualitative assessment but these were minor and repaired by the contractor. Of the 180 tiles LAS files reviewed, all 180 were initially rejected due to a failure in the vertical accuracy assessment (See Appendix F). In addition, some tiles were flagged for improper classification in areas where ground points were found in water bodies. The redelivery of the data was checked thoroughly and passed. The following table and associated screenshots is representative of the issues found in water bodies and of the random gaps explained earlier in this report:

Points		
Tile	**Issue**	**Code**
LID 043840	Ground points in water body	Corrected
LID 048687	Gaps in parking lots	Pass
LID 048151	Gaps on buildings	Pass

LID 043840 – in several areas ground points were found in the .LAS files that should have been classified as water (see Figure 7). This was likely due to an automated filter confusing the points with ground points, based on elevation. These tiles were rejected and subsequently corrected by the mapping vendor.

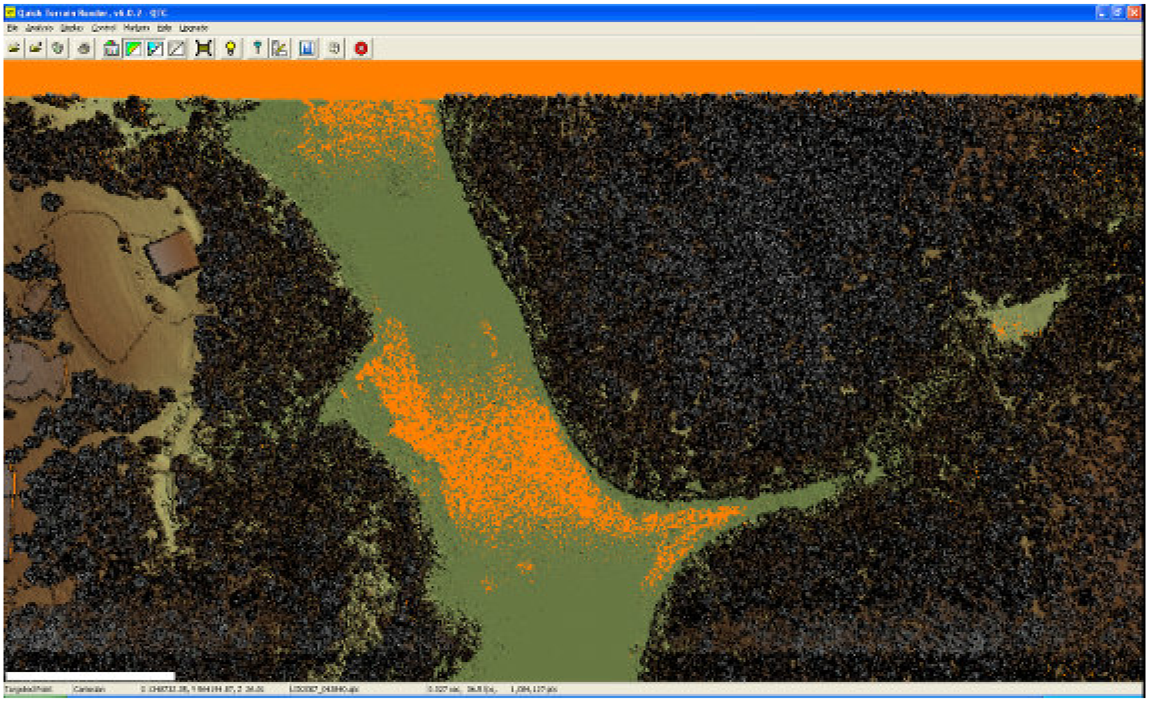

Figure 15 Tile 043840 – example of points classified as Class 2- ground points in a water body.

LID 048687 - example of gaps over paved surfaces. In this example (Figure 8) no returns were registered by the LiDAR sensor in large areas of this commercial parking lot (dropped points).

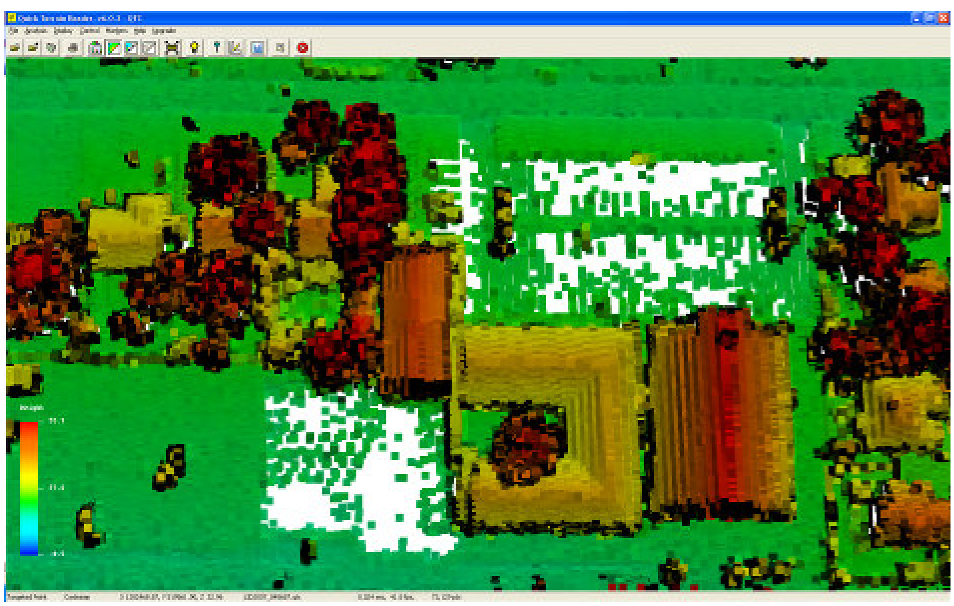

Figure 16 Tile 048687 – ground points not present in parking lot, causing gaps

LID 048687 - example of gap on rooftop of commercial building. In this example (Figure 9) no returns were registered by the LiDAR sensor over a portion of this building (dropped points).

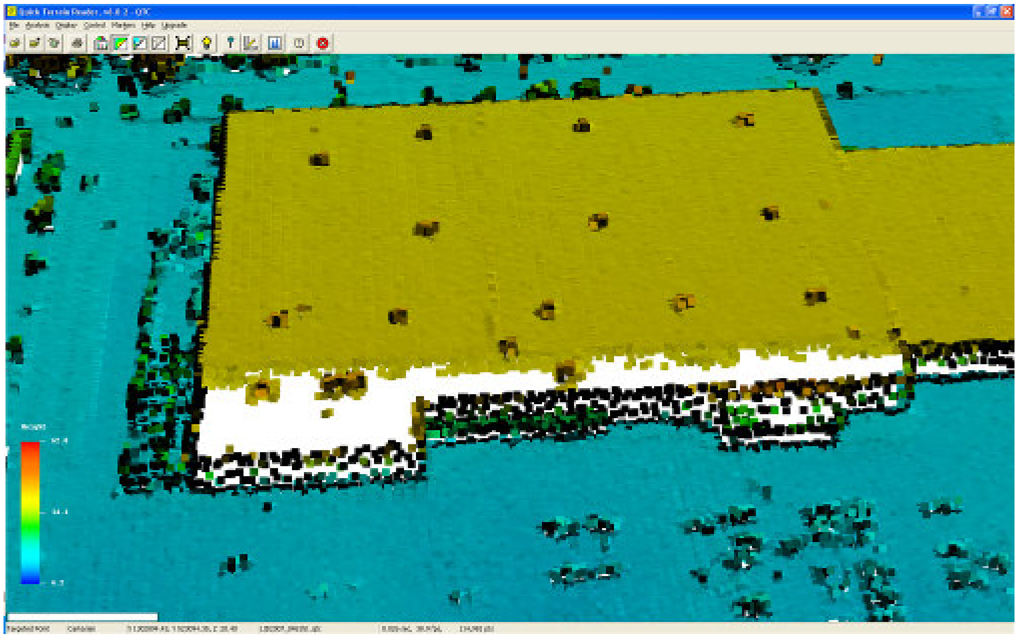

Figure 17 Tile 048151 - no points on building roof causing gap (oblique viewpoint)

Conclusion

Overall the data meets the project specifications. The classification of the raw point cloud to bare ground was executed well given the low terrain relief and areas of dense vegetation. The data did fail the initial vertical accuracy assessment and contained areas of improperly classified water points; however these issues were corrected for by the vendor and were not present in the redelivered data. The Okaloosa County data set was deemed acceptable to be incorporated into the overall FDEM LiDAR derived terrain surface model.

During the PDS quality analysis of the Okaloosa LiDAR data it was evident that "dropped points" occurred sporadically on features throughout the county. Dropped points are characterized by points missing on features such as building roofs, parking lots, and other paved surfaces. The magnitude of dropped points observed in this particular data set is typically caused by issues with the Automatic Gain Control (AGC); either AGC sensor settings or the problems with the ACC card in the sensor.

It is the PDS opinion that the dropped points observed in the Okaloosa County data set do not pose a significant decrease in the overall accuracy of the terrain surface data or contours.

Appendix H: Breakline/Contour Qualitative Assessment Report

Coastal Shorelines

Coastal shorelines are correctly captured as two-dimensional polygon features, extracted from the LiDAR data and not from digital orthophotos, except for manmade features with varying heights such as seawalls which are captured as three-dimensional breaklines. Coastal breaklines merge seamlessly with linear hydrographic features. Shorelines continue beneath docks and piers. There is no “stair-stepping” of coastal shorelines. Figure 1 shows example coastal breaklines and contours.

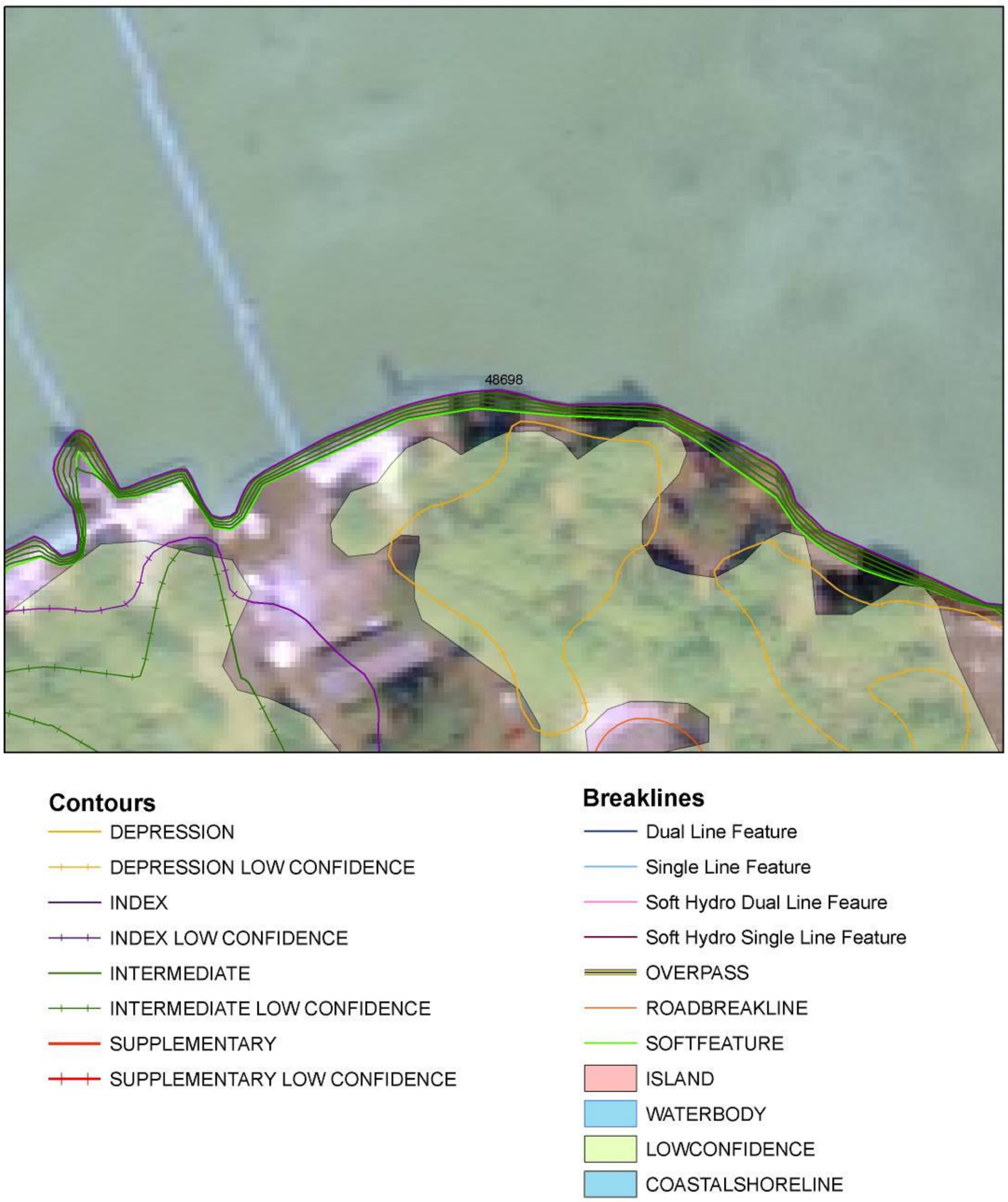

Figure 1. Example coastal breaklines and contours from tile #48698

Linear Hydrographic Features

Linear hydrographic features are correctly captured as three-dimensional breaklines – single line features if the average width is 8 feet or less and dual line features if the average width is greater than 8 feet. Each vertex maintains vertical integrity. Figure 2 shows example breaklines and contours of linear hydrographic features.

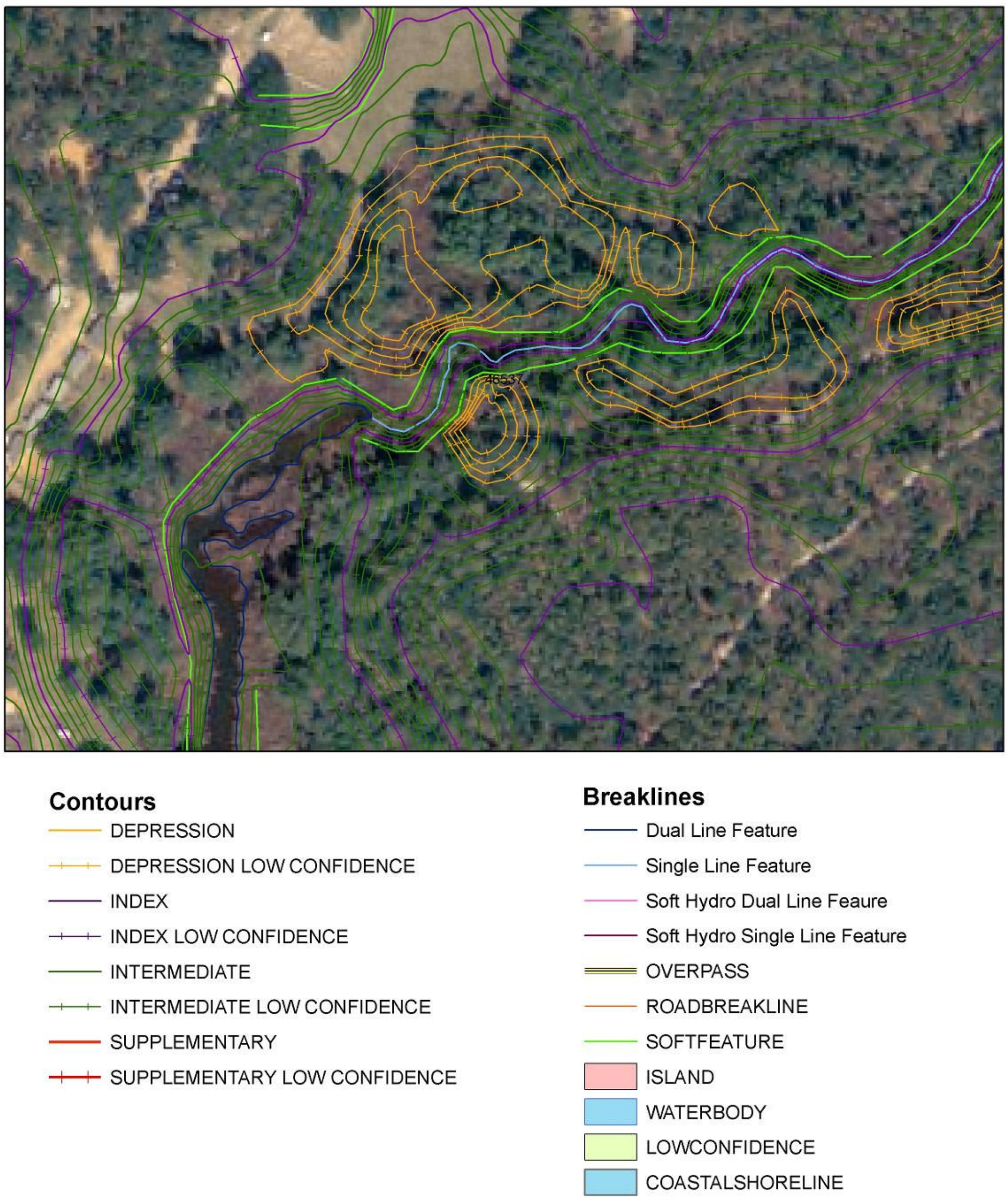

Figure 2. Example linear hydrographic feature breaklines and contours from tile # 46537

Closed Water Body Features

Closed water body features with an area of one-half acre or greater are correctly captured as two-dimensional closed polygons with a constant elevation that reflects the best estimate of the water elevation at the time of data capture. “Donuts” exist where there are islands within a closed water body feature. Figure 3 shows example breaklines and contours of closed water body features.

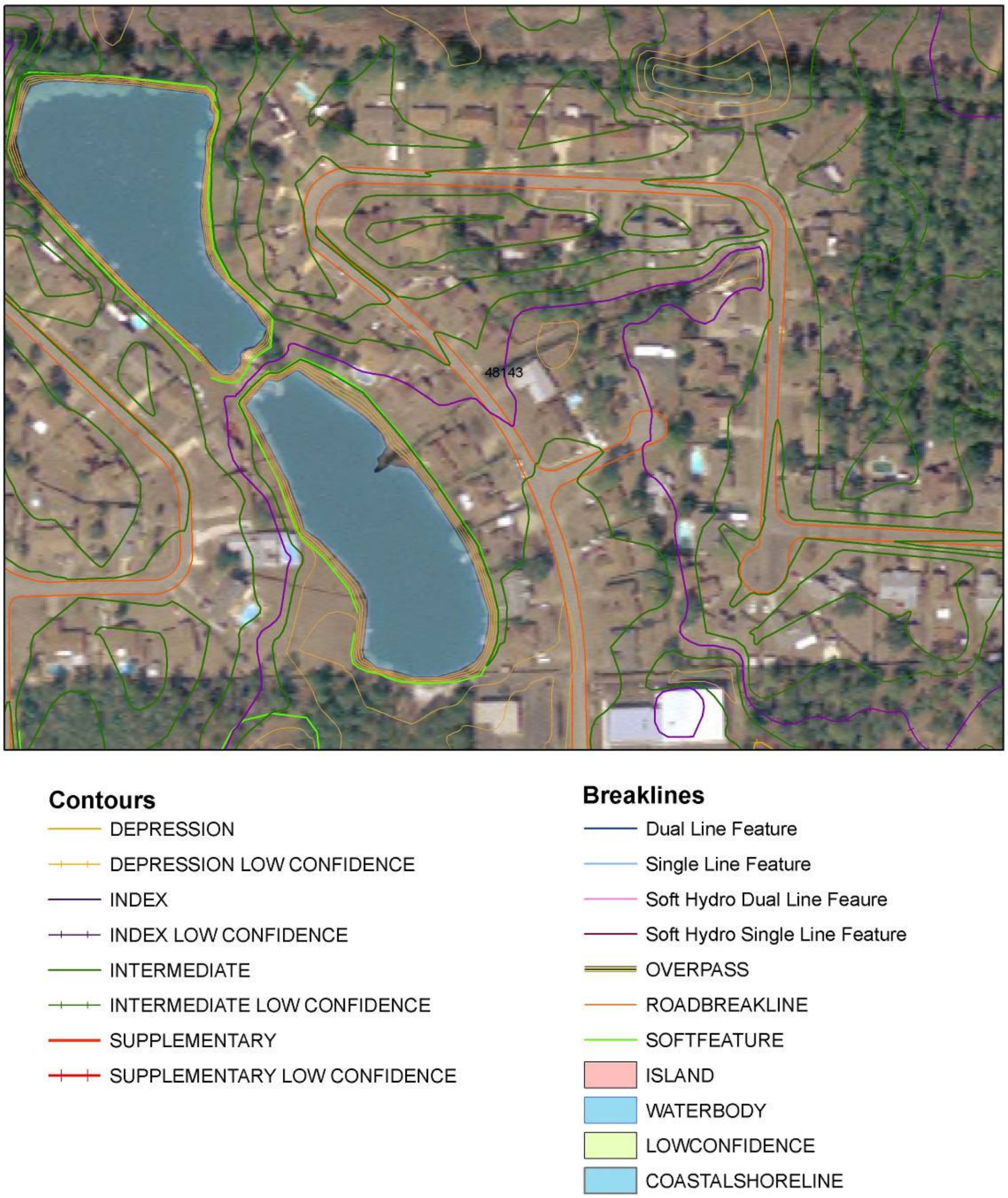

Figure 3. Example closed water body feature breaklines and contours from tile #48143

Road Features

Road edge of pavement features are correctly captured as three-dimensional breaklines on both sides of paved roads. Box culverts are continued as edge of pavement unless a clear guardrail system is in place; in that case, culverts are captured as a bridge or overpass feature. Each vertex maintains vertical integrity. Figure 4 shows example breaklines and contours of road features.

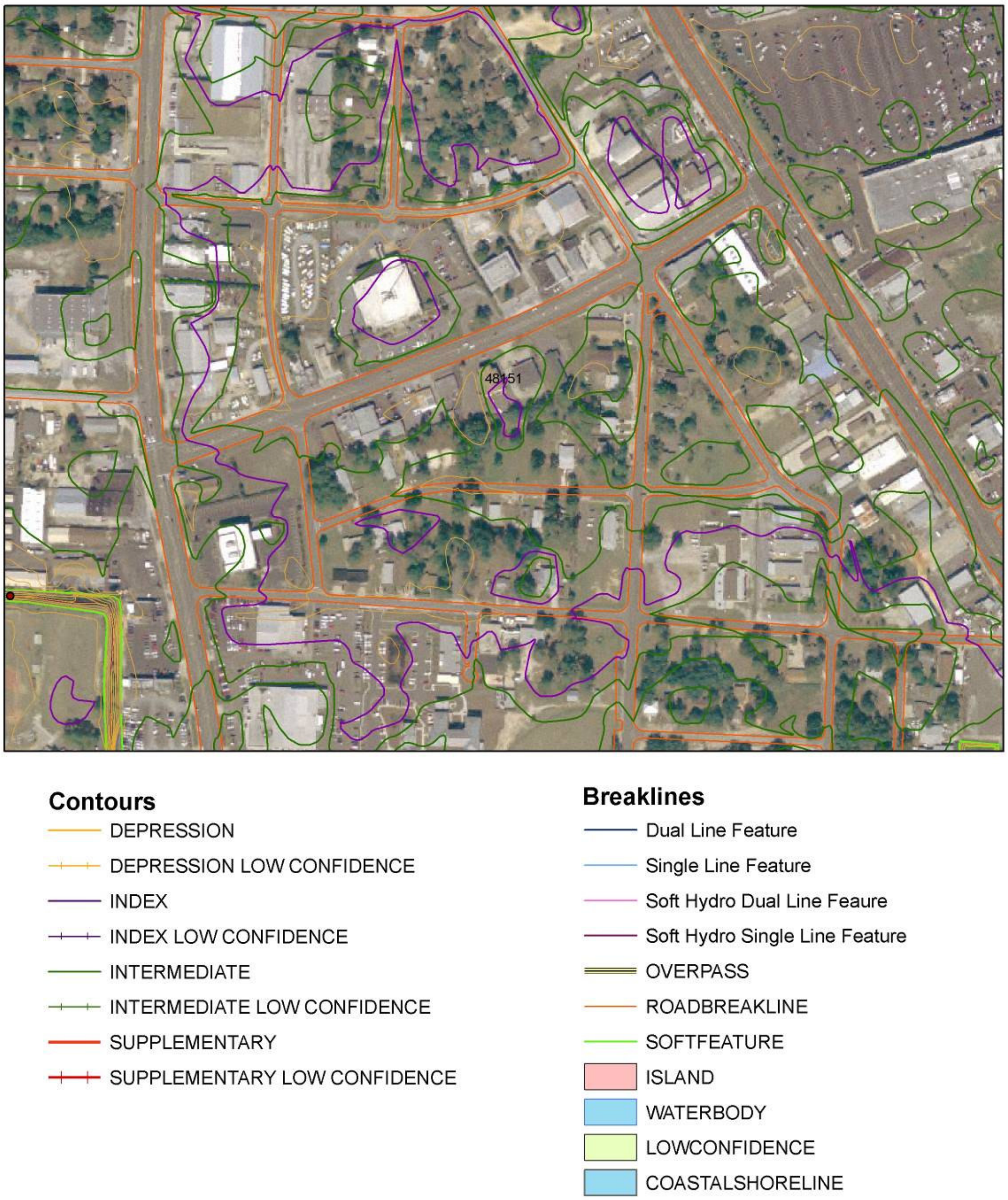

Figure 4. Example road feature breaklines and contours from tiles #48151

Bridge and Overpass Features

Bridges and overpasses are correctly captured as three-dimensional breaklines, capturing the edge of pavement on the bridge, rather than the elevation of guard rails or other bridge surfaces. Each vertex maintains vertical integrity. Figure 5 shows example breaklines and contours of bridge and overpass features.

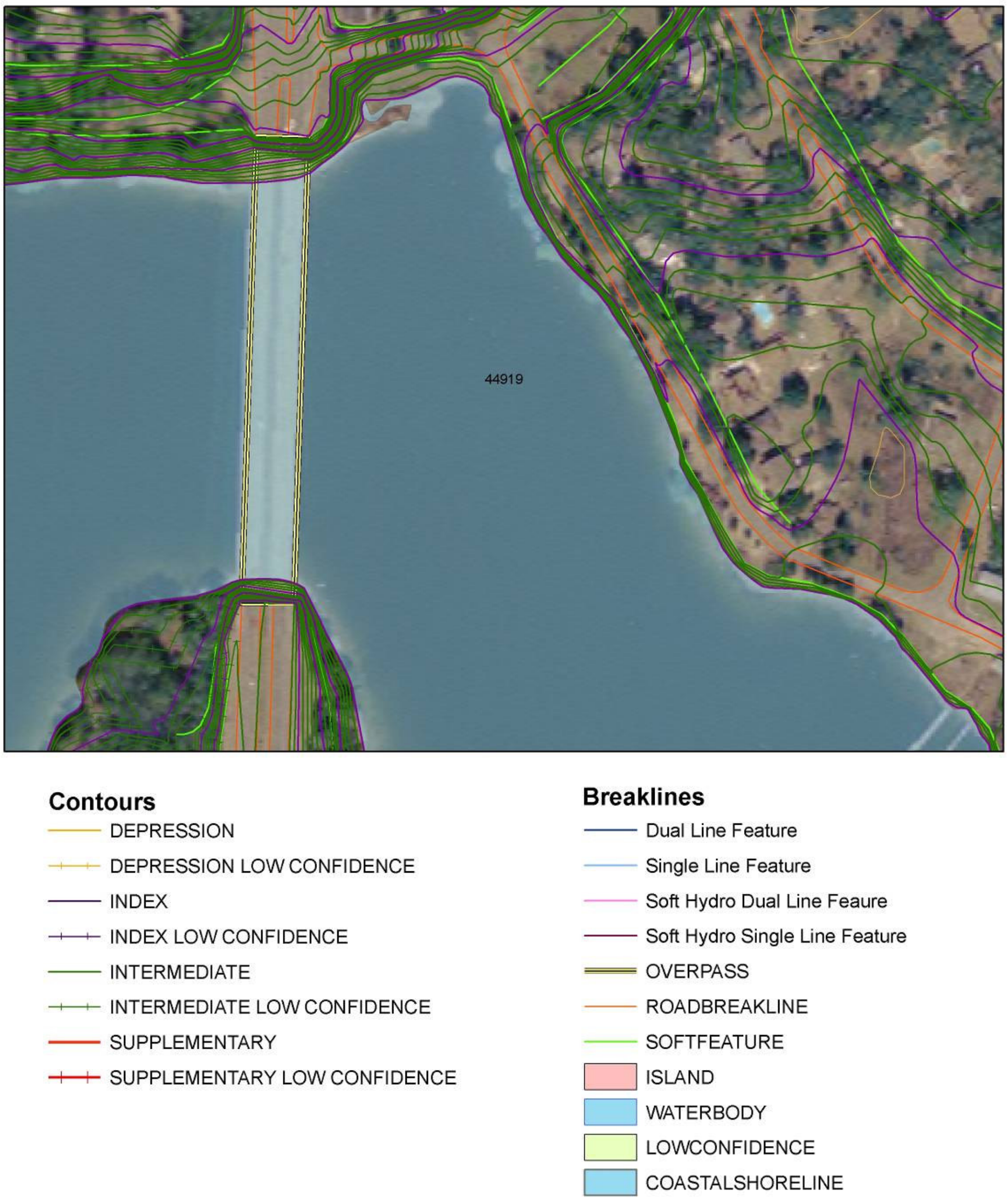

Figure 5. Example bridge and overpass feature breaklines and contours from tile # 44919

Soft Features

Soft features such as ridges, valleys, top of banks, etc. are correctly captured as three-dimensional breaklines so as to support better hydrological modeling of the LiDAR data and contours. Each vertex maintains vertical integrity. Figure 6 shows example breaklines and contours of soft features.

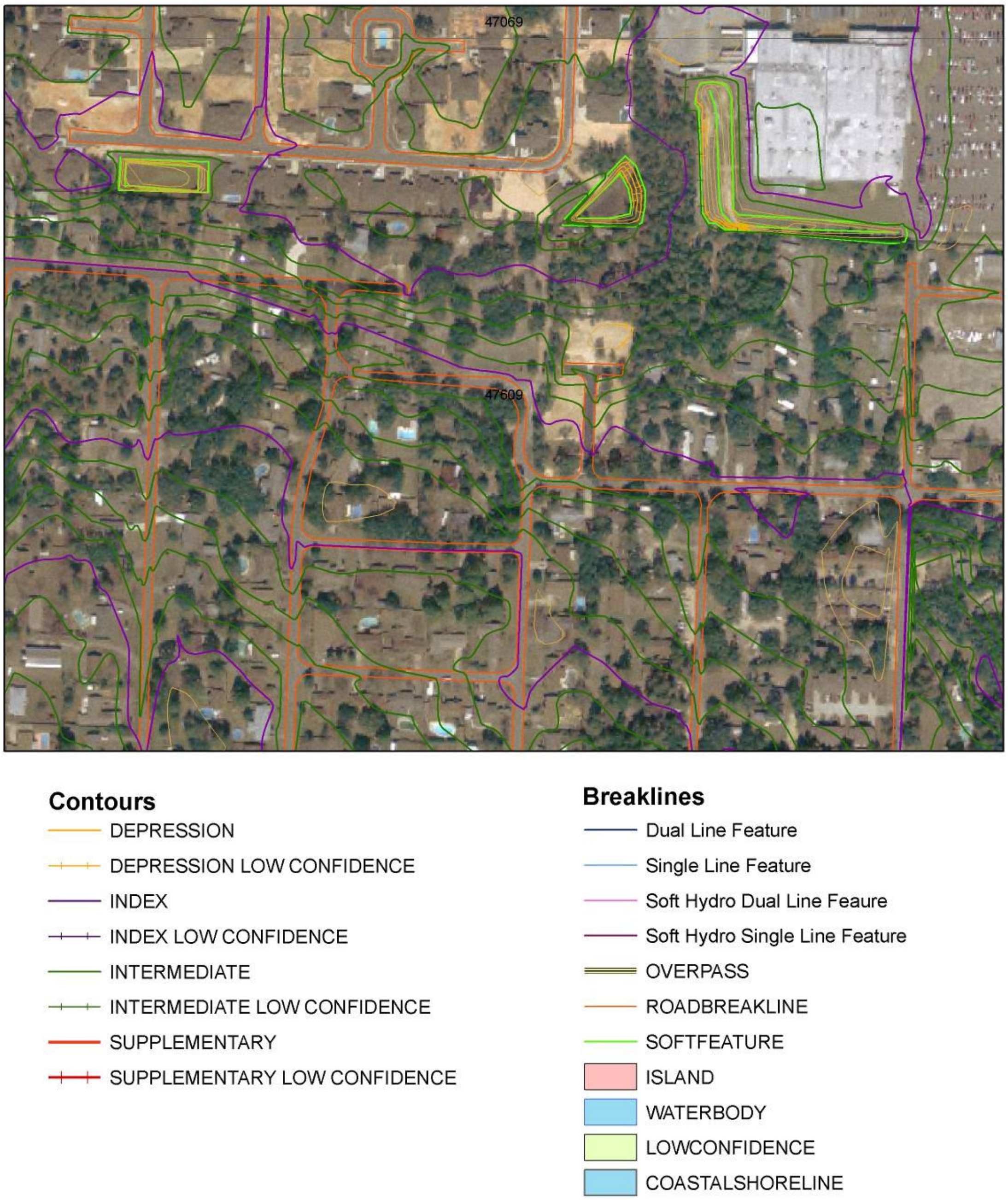

Figure 6. Example soft feature breaklines and contours from tile #47609

Island Features

The shoreline of islands within water bodies are correctly captured as two-dimensional breaklines in coastal and/or tidally influenced areas and as three-dimensional breaklines in non-tidally influenced areas for island features one-half acre in size or greater. All natural and man-made islands are depicted as closed polygons with constant elevation. Figure 7 shows example breaklines and contours for island features.

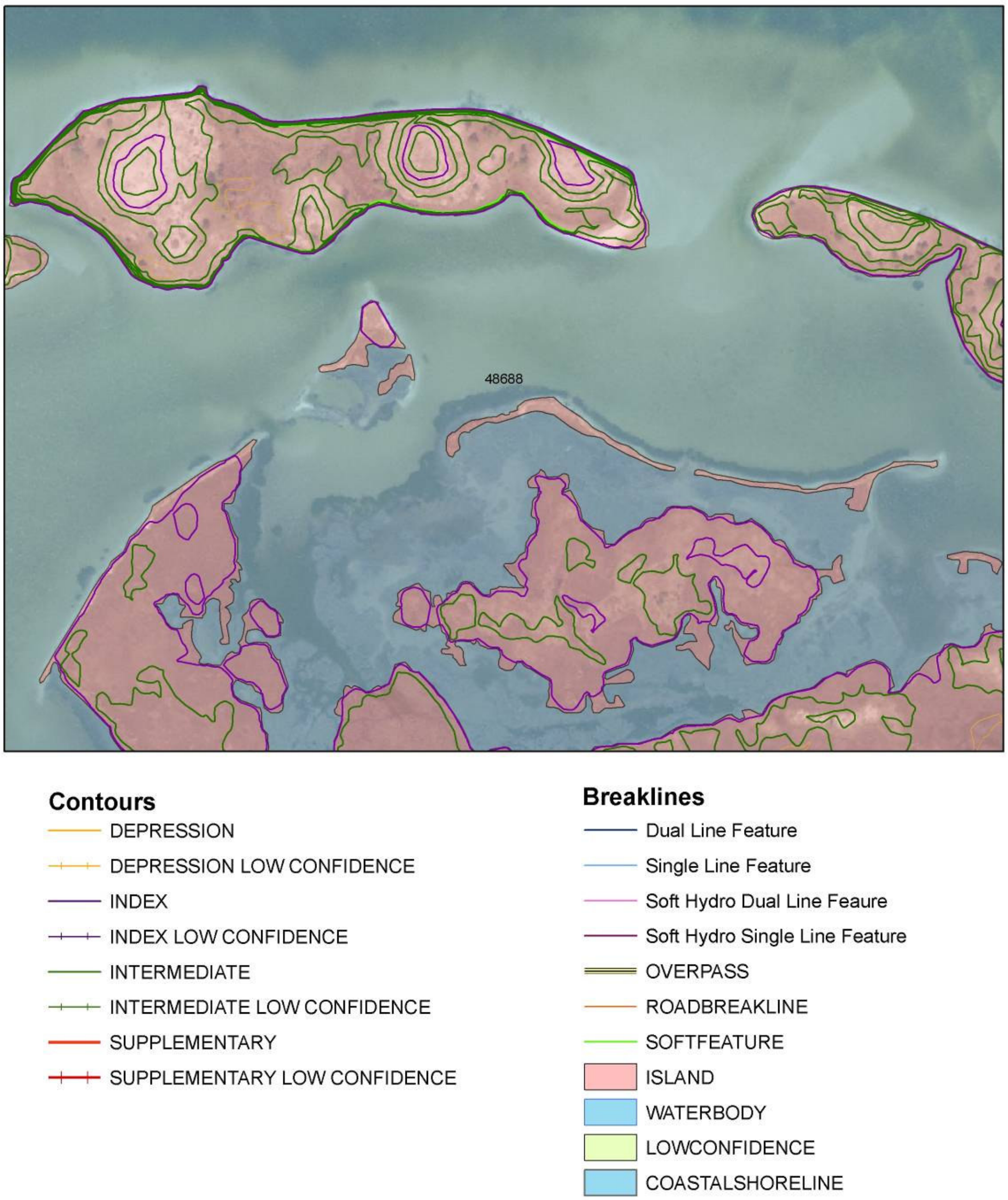

Figure 7. Example island feature breaklines and contours from tiles # 48688

Low Confidence Areas

The apparent boundary of vegetated areas (1/2 acre or larger) that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM are correctly captured as two-dimensional features with no z-values. Figure 8 shows example breaklines and contours for low confidence areas.

Figure 8. Example low confidence area feature breaklines and contours from tile # 48148 & 48688

Appendix I: Geodatabase Structure